Carbonate Sedimentology of the Late Early to Middle Devonian Limestone Members of the Yarrimie Formation, Manilla, NSW

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POHLER, S.M.L. (1998). Carbonate sedimentology of the late Early to Middle Devonian limestone members of the Yarrimie Formation, Manilla, NSW. *Proceedings of the Linnean Society of New South Wales* **120**, 11–41.

The Sulcor and Moore Creek Limestone Members of the siliciclastic and volcaniclastic Yarrimie Formation occur east of Manilla, NSW. The limestones are exposed in two continuous belts on the eastern limb of the Yarramanbully anticline. The Sulcor Limestone Member at Yarramanbully is late Emsian in age and is a northern equivalent of the Sulcor Limestone Member near Attunga. The Moore Creek Limestone Member is middle to late Eifelian to possibly early Givetian in age. It is a northern equivalent of the Moore Creek Limestone Member near Attunga and near Tamworth. In both units the base is not exposed and the top of the older limestone is erosional; the top of the younger limestone is covered or faulted, and possibly erosional in the north. A number of disconnected small limestone bodies in the vicinity are interpreted as tectonic fragments, olistoliths and clasts in megaconglomerates.

All limestones are of shallow marine origin; the older Sulcor equivalents were deposited in shallow quiet water, the younger Moore Creek equivalents include basal reworked sediments changing upwards to massive shallow marine carbonates. In both limestones a deepening upward trend is observed and there is some indication that the northern limestones where deposited in shallower water than the southern ones, suggesting deposition on a bathymetric gradient.

Manuscript received 21 May 1997, accepted for publication 17 June 1998.

KEYWORDS: Devonian, Emsian, Eifelian, Givetian, Tamworth Group, Yarrimie Formation, Moore Creek Limestone Member, Sulcor Limestone Member, carbonate sedimentology, biostromes.

INTRODUCTION

Scattered limestone bodies largely of Devonian age are abundant in the Tamworth Belt of NSW (Fig. 1). Limestones belonging to the Emsian to Givetian Sulcor and Moore Creek Limestone Members of the Yarrimie Formation are exposed in the Yarramanbully region (Fig. 2) approximately ten kilometres east of Manilla (NSW) extending southward over six kilometres.

The purpose of this paper is to document recent geological mapping and sedimentological studies of the limestones in the Yarramanbully region. The area was mapped on 1:25 000 scale airphotos. The field data were transposed onto the 1:25 000 scale topographic map (map sheet KLORI 9036–II–N; Central Mapping Authority of NSW) (Fig. 3). Sections were measured through key locations with good exposure and minor deformation.

GEOLOGICAL SETTING

Large limestone bodies informally known as the Yarramanbully limestones of the Yarrimie Formation (Chappell 1961; Crook 1961; McMinn 1977, 1982) are exposed on

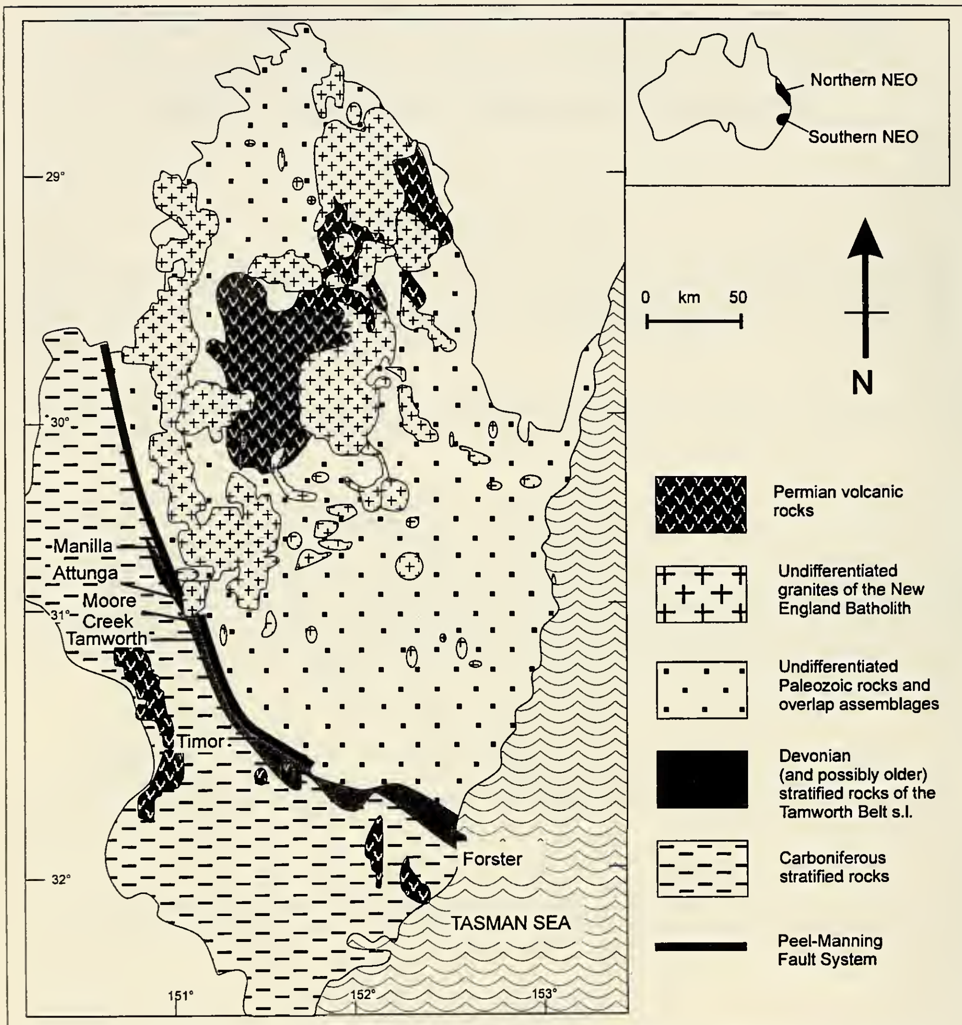

Figure 1. Simplified geological map of the southern New England Orogen (NEO) with locations mentioned in the text.

the eastern limb of the Yarramanbully Anticline (Voisey 1958) (Fig. 3). The anticline is faulted at or near the hingeline and older rocks are exposed on the eastern limb than on the western limb (Fig. 4).

The stratigraphic sequence begins with the lower Yarramanbully limestone, herein referred to as the Sulcor Limestone Member (Crook 1961), which is exposed over a distance of approximately 3.5 kilometres with a regionally consistent NNW-SSE strike. Its base is truncated to the west by a north-south trending fault. The limestone dips to the southeast at moderate angles and is complicated by folding and faulting. Folding has thickened the limestone particularly in its northern and central parts; its true thickness probably does not exceed 200m. To the south it ends abruptly along a steeply SW dipping fault (GR Klori 916 926). The top of the lower limestone is eroded with conglomerates forming up to 25m thick and 500m wide channels incising the uppermost beds of the

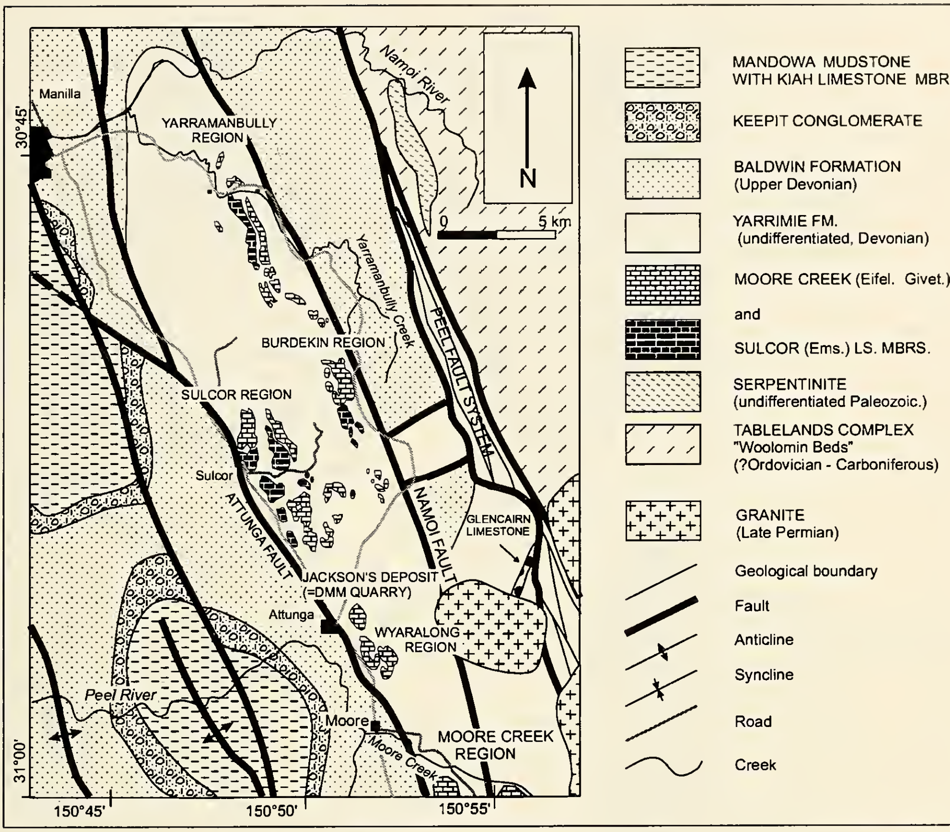

Figure 2. Simplified geological map of the Attunga region locating the limestone bodies. Geology based on 1 : 250 000 Geological Series Sheet Manilla (SH 56–9) published by the N.S.W. Department of Mines, 1966.

succession. A fault separates the lower limestone and overlying siliciclastic sediments from those underlying the upper limestone member. It hence appears that the Sulcor Limestone Member is a fault-bounded block. Chappell (1961) commented that many of the limestone bodies in the Tamworth Belt are limited by faulting. Pedder (1967: 138) commented, that Crook (1961) determined the Sulcor coral *Phillipsastrea maculosa* from the Silver Gully Fm. southeast of Tamworth. This implies that the Silver Gully Fm. (which underlies the Yarrimie Fm. in the type section at Silver Gully) is probably in part younger than the Sulcor Limestone Member. Hence the Sulcor Limestone may be regarded as a member of the Silver Gully Fm. The stratigraphy of the Tamworth Belt limestones and volcaniclastics is currently under review (Mawson and Talent in prep.; E. C. Leitch pers. comm. 1997).

Above the lower limestone follows the lower Yarrimie Formation with 100m to 350m of wavy bedded bioturbated silicified siltstones, mudrocks, and minor arenites and conglomerates (Fig. 5A). The actual limestone/siliciclastic contact is nowhere exposed but interbedded siltstones and grainstones have been found immediately above the contact in the central part of the outcrop area. The lithologies of the lower Yarrimie Formation are very similar to those seen below the Moore Creek Limestone Member at Wyaralong (Pohler and Herbert 1993) and Jackson's Deposit (Mawson and Talent 1994). Manser (1968) observed a similar sequence below the Timor Limestone and felt that it

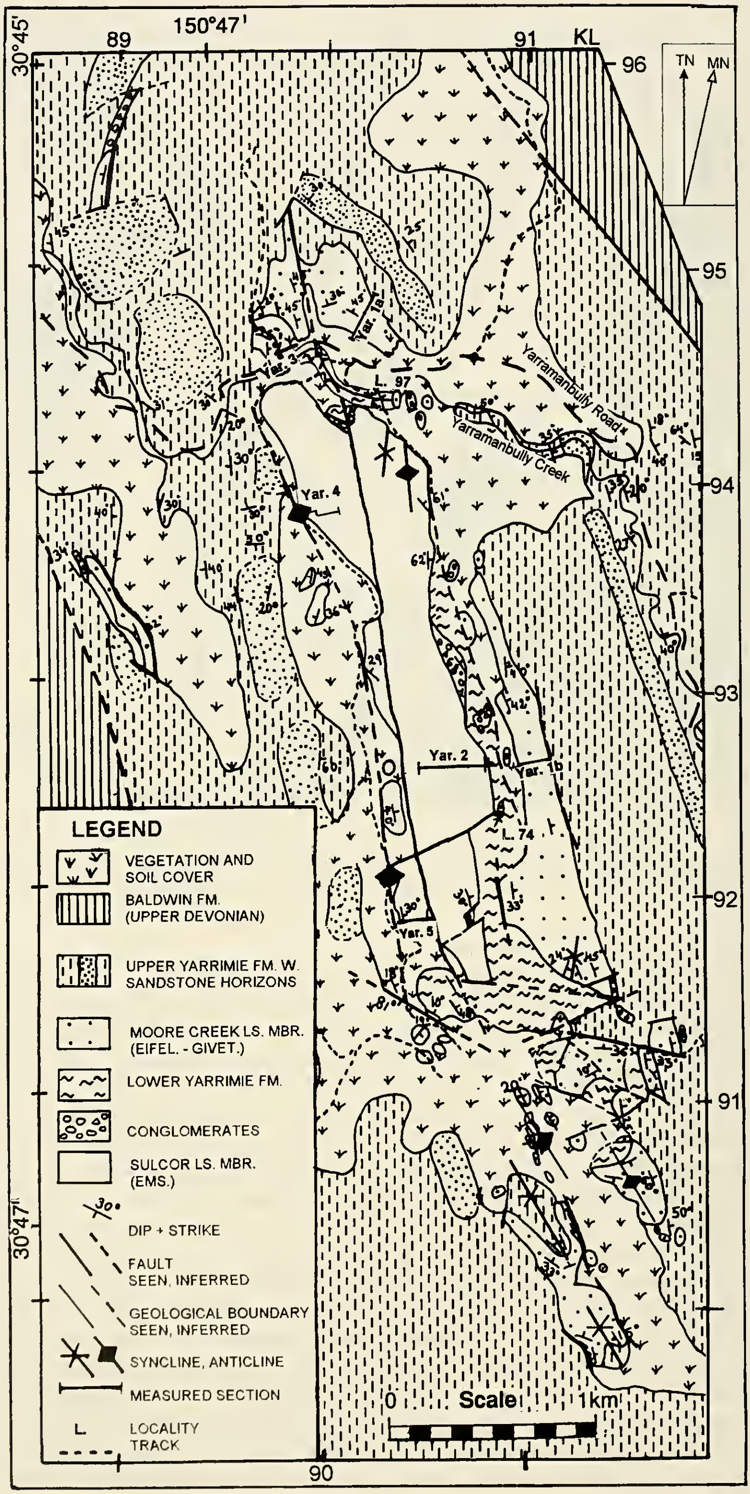

Figure 3. Geological map (based on topographic map 1:25 000 Klori 9036–II-N) of the Sulcor and Moore Creek Limestone Members and adjacent sediments in the Yarramanbully region.

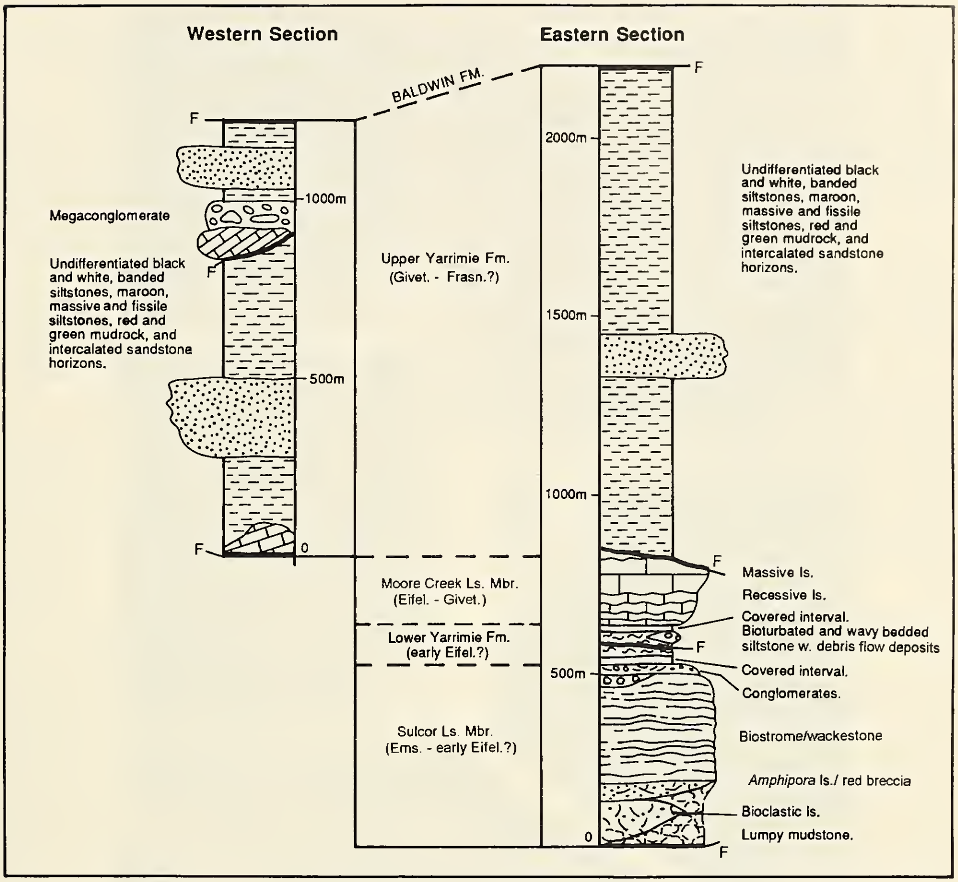

Figure 4. Generalized composite sections of the Yarrimie Formation with limestone members east and west of the anticlinal hinge. Thicknesses are apparent and estimated for some intervals.

was sufficiently different from the upper Yarrimie Formation to warrant sub-division of the formation. He referred the lower sequence to the Lilberne Beds and the upper mixed volcaniclastic/siliciclastic sediments to Busches Formation. This sub-division of the Yarrimie Formation appears to also be valid in the northern part of the Tamworth Belt. However, because the Yarrimie Formation was defined earlier (Crook 1961) it takes precedence over Manser's definitions and his Lilberne Beds and Busches Formation should possibly be assigned member status within the Yarrime Formation. In addition it is possible that the lower Yarrimie Fm. is in part age-equivalent to the Silver Gully Fm. southeast of Tamworth (Pedder 1967). The lithologies, however, are quite different and therefore Mawson et al. (in press) referred to the lower Yarrimie Fm. as "unnamed unit", pending clarification of the stratigraphic relationships.

The lower Yarrimie Formation is succeeded by the Moore Creek Limestone Member up to 200m thick, extending over six kilometres from north to south in a number of laterally discontinuous and fragmented limestone bodies. The most continuous exposures are located in the northern and central eastern part of the map area.

The base of the upper limestone is not exposed. The top appears to be erosional in the north, where sporadic ferruginous red breccias occur; in the central part some of the

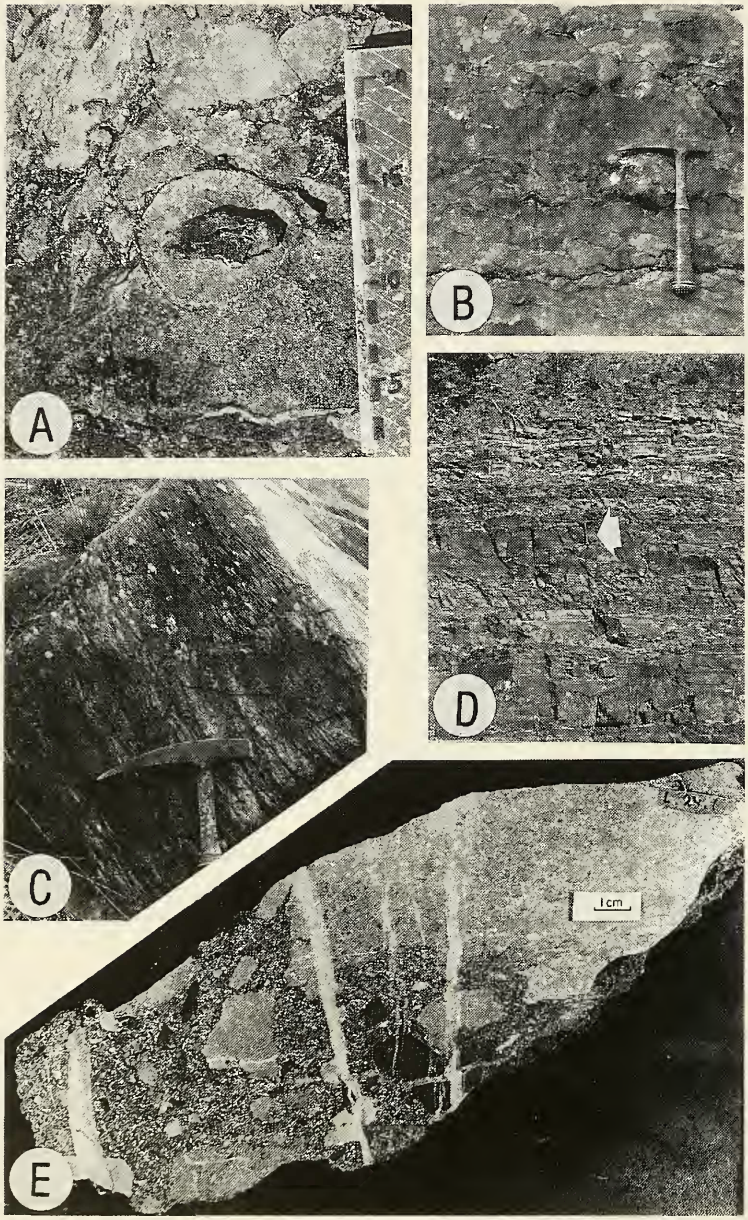

Figure 5A. Conglomerate in the lower Yarrimie Formation (central part of Yarramanbully area at L. 74, see Fig. 3 for location). Light grey rounded limestone clasts are set in a silicified siltstone matrix. Note corallite of *Pseudamplexus princeps* in centre. Figure 5B. Nodular to bedded limestone found near the top of the Sulcor Limestone in the bed of Yarramanbully Creek at Yar. 3 (see Fig. 3 for location). The lighter coloured sediment between the nodules is red and green mudrock to siltstone. Figure 5C. Mylonitic limestone in loose block adjacent to the fault at the hinge of the Yarramanbully anticline, limiting the limestones to the west (GR Klori 903 947). Figure 5D. Black and white banded siltstones, thick bedded and fissile siltstones characteristic of the upper Yarrimie Formation in the bed of Yarramanbully Creek below Yarramanbully Road. Note scale provided by geological hammer (arrow). Figure 5E. Polished slab of clasts and matrix found in the megaconglomerate unit north of "Cashel". Light grey clasts are limestone, dark clasts are red mudrock. Small white grains are in part feldspar laths.

upper sequence is missing due to faulting, or is covered. To the south the limestone is complexely folded, faulted and fragmented. Basal and top contacts are commonly sheared and/or the limestone bodies are not in stratigraphic order (Fig. 3).

Above the limestone follows the upper Yarrimie Formation with an apparent thickness of over 1.5km. The sequence consists of maroon massive and fissile siltstones, tuffaceous black and white banded siltstones, red and green silicified mudrocks and intercalated coarse sandstones. Figure 5D illustrates a characteristic succession at Yarramanbully Creek. A fault separates the Yarrimie Formation from overlying sediments assumed to be time-equivalent with the Baldwin Formation (McMinn 1982).

As mentioned above, the eastern limb of the Yarramanbully anticline is separated by a fault from the western limb. This fault can be inferred at GR Klori 903 947 where mylonitic limestones occur in loose blocks adjacent to the fault (Fig. 5C). The fault continues in a southward direction along the base of the lower limestone and disappears under drift at the end of the limestone outcrop.

The sequence on the western limb probably belongs to the upper Yarrime Formation suggesting that it is down-faulted. A number of small west-dipping limestone outcrops occur immediately to the west of the faulted anticlinal hinge. They contain corals such as *Pseudamplexus princeps* and lithologies (i.e. echinoderm grainstone) characteristic of the Sulcor Limestone Member. They are overlain to the west by upper Yarrimie siltstones and sandstones and hence are not in stratigraphic order. They may represent small faultblocks which were emplaced adjacent to the larger fault structure to the east.

Two disconnected limestone bodies in the northwest (GR Klori 891 965) and far west (GR Klori 890 931) (Fig. 3) are associated with conglomerates (Fig. 5E) and surrounded by upper Yarrimie lithologies suggesting that they are either blocks in megaconglomerate units or faulted-in slivers of older lithologies. Faults can be seen or inferred limiting the northern outcrop at the base and to the north; the southwestern outcrop is faulted to the south and probably at the base were loose blocks of mylonitic limestone occur. The age of these two large masses has so far not been ascertained because no conodonts were recovered (R. Mawson pers. comm. 1995). The lithologies are not similar to those of the eastern limestone outcrops or elsewhere in the area.

Marshall (1968) suggested that the limestone bodies on the western limb of the anticline are of mixed age based on the co-occurence of *Phillipsastrea linearis* (Hill) and *Sociophyllum* n. sp. Pedder. The latter coral was also found in the present study along with a number of *Phacellophyllum* sp. (J. Pickett pers. comm. 1994). The presence of a mixed coral fauna is consistent with the conglomeratic nature of the unit.

Disconnected limestone outcrops in the southern part of the map area are commonly faulted and folded with a sheared base. Their lithologies suggest that they are fragments of the Moore Creek Limestone Member. Most are not in stratigraphic order but are over- and underlain by upper Yarrimie Formation suggesting that they are either tectonic fragments or olistoliths.

BIOSTRATIGRAPHY

Chappell (1961) was the first to investigate fossils from limestones in the Yarramanbully region. He reported the presence of abundant *Pseudamplexus princeps* (Etheridge) south of Yarramanbully Creek and suggested that these rocks are correlative to the Sulcor Limestone. Marshall (1968) also found *P. princeps* in the lower Yarramanbully limestone in addition to a number of other rugose corals namely *Phillipsastrea linearis* (Hill), *Trapezophyllum coulteri* Hill, *Tipheophyllum* n. sp., *Phacellophyllum* sp., *Plasmophyllum* sp., and *Thamnophyllum* sp. All of these rugose corals were previously reported by Hill (1943) and Pedder (1967, 1970) from the Sulcor

Figure 6. Facies distribution in the Sulcor and Moore Creek Limestone Members at Yarramanbully. For distribution of soil and vegetation, upper Yarrimie Formation and areas further south see Fig. 2.

Limestone Member. Phillip and Pedder (1967) concluded that late Emsian is the latest occurrence of *P. princeps*.

Marshall (1968) reported a different coral fauna from the conglomerate at the top of the lower Yarramanbully limestone with *Macgeea touti* Pedder and other corals of Pedder's (1967, 1970) Sulcor Fauna C. Numerous corals were collected from the conglomerate for the present study but *M. touti* was not found. However, the limestone facies which contains Fauna C at Sulcor (thinly bedded biostromal boundstone with silicified tabular and laminar stromatoporoids and tabulate corals) is missing at the top of the Yarramanbully limestone. It is likely that the conglomerate contains eroded remains of the topmost unit of the sequence with the youngest faunas. *M. touti* occurs in an interval straddling the Emsian/Eifelian boundary (Philip and Pedder 1967).

Conodonts from the upper Yarramanbully limestone were investigated by Mawson et al. (1988, p. 500). Their measured and sampled section in the valley of Yarramanbully Creek commences at grid reference 94609021 on the New South Wales Central Mapping authority 1:25,000 topographic map Klori, 9036–II-S. The conodont fauna recovered indicates the section to begin in *australis* Zone (mid Eifelian). At 14.7m above the base of the section, the incoming of *Polygnathus eiflius* is indicative of *kockelianus* Zone (late Eifelian). This age is consistent with that given for portion of the Moore Creek Limestone cropping out in the vicinity of Attunga and Tamworth (e.g. Philip 1967; Mawson and Talent 1994; Klyza 1995; and Mawson et al. 1997).

CARBONATE LITHOFACIES

The facies of the Sulcor and Moore Creek Limestone Members were mapped in the northern part of the area based on 1:25 000 scale aerial photographs, enlarged to 1:10 000 (Fig. 6). Several sections were measured through both limestones on the eastern limb of the Yarramanbully anticline and through the two limestone bodies exposed on the western limb (Yar. 1–4). Locations and designations are indicated on Figure 3; stratigraphic columns of selected sections are illustrated in Figs 7, 9, 10 and 12. Units are described in ascending order beginning with the Sulcor Limestone Member. Terminology used for descriptions is that of Dunham (1962), Folk (1962), Pettijohn (1957), and Grabau (1903, outlined in Folk 1968).

Sulcor Limestone Member

Coarse bioclastic limestone

This lithofacies crops out along the track to the SW end of the Sulcor Limestone Member (GR Klori 901 938). Its base is not exposed, the top is conformably overlain by the dark lumpy wackestone. The facies cannot be followed laterally to the south because it is cut off by a fault. To the north it interfingers with the lumpy wackestone facies. It is at least 100m thick at Yar. 4 where it forms massive outcrops of light grey to grey rudstone or biosparrudite interbedded with and grading upwards into finer-grained lithologies (Fig. 7). The basal calcarenites and calcirudites are composed of diverse very coarse sand- to pebble- sized fossil fragments; thin sections show the fossil debris to be dominantly derived from echinoderms, with subordinate stromatoporoids, *Stachyodes*, rugose and tabulate corals, algae and brachiopods. Lithoclasts of wackestone are rarely found. The finer-grained lithologies are packstones and grainstones with fine to medium sand-sized allochems with a higher mud fraction and stylo-flaser bedding but otherwise similar composition. Near the top of section Yar. 5 (not figured) occur finer-grained bioclastic limestones above the lumpy wackestone indicating that this lithology is not restricted to the base of the lower limestone.

Many of the fossil fragments have micritic envelopes, particularly the echinoderm and shell fragments. In many cases the original structure of a skeletal fragment has been completely obliterated by recrystallization, leaving only a mosaic of coarse crystalline calcite surrounded by a thin rim of micrite. Most components are rounded to subrounded, with low sphericity, and poor sorting.

Interpretation

Rounding and lack of lime mud between components suggests high water energy. However, micrite envelopes are caused by microbial decay (Bathurst 1966, 1975; Alexandersson 1972) and this degradation may have contributed to their roundness. The

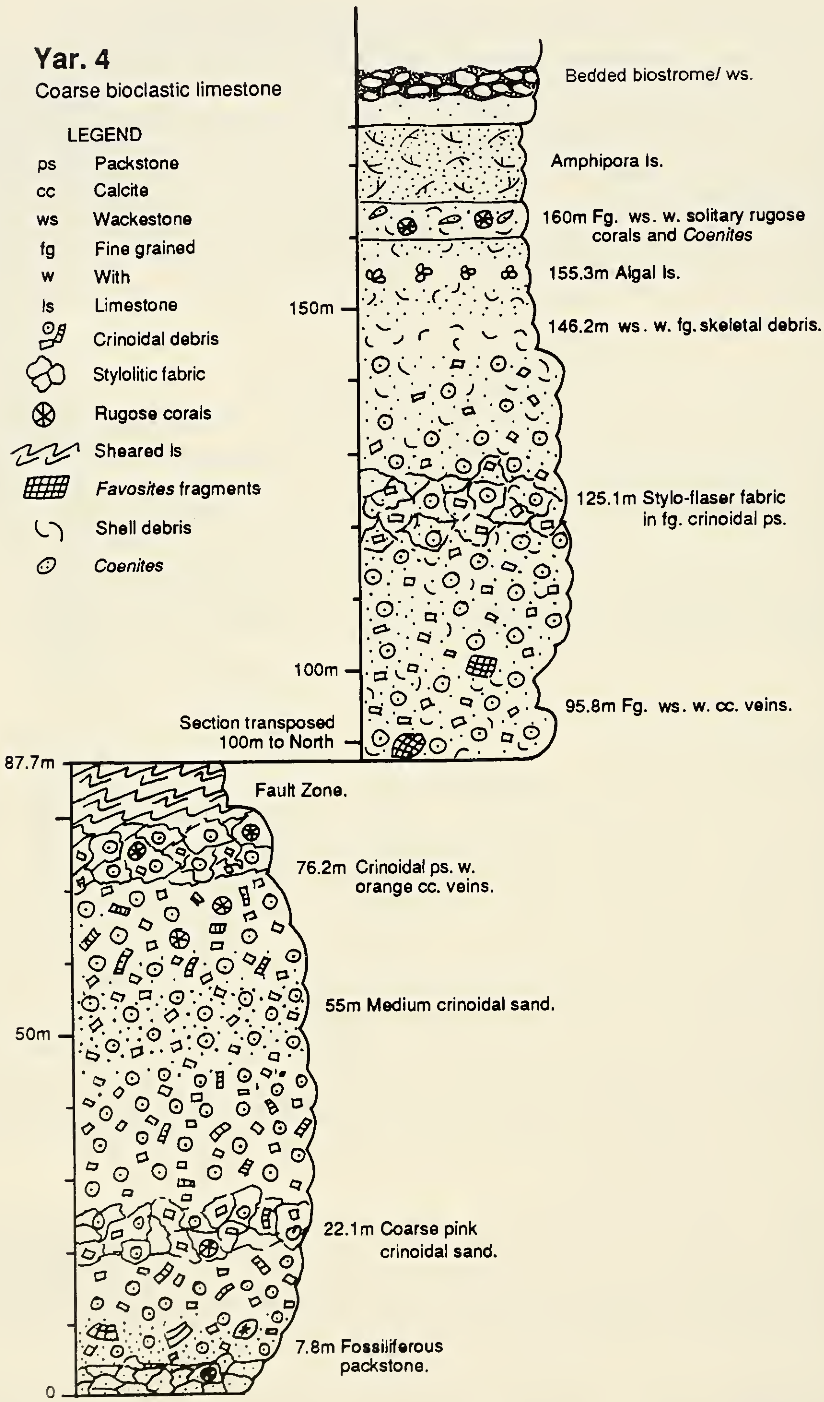

Figure 7. Section Yar. 4 through the basal echinoderm rudstone and grainstone, Sulcor Limestone Mbr. (see Fig. 3 for location).

amount of neomorph spar and dusty inclusions in the ground mass suggests that originally the limestone contained more mud (Bathurst 1975). Hence water energy may have been lower than indicated by the present texture and composition. The sediment is almost entirely composed of debris from baffling and frame-building organisms. Its large size and lack of sorting suggests that no distant transport occurred, but that breakdown and reworking was close to their life position. The extensive replacement of early aragonitic and calcitic cements suggests that the sediment was exposed to meteoric or even vadose diagenesis. The sporadic occurrence and lateral discontinuity of the sediment implies a lenticular outcrop pattern. It may be that the bioclastic limestone formed in shoal areas colonized by crinoids and other organisms below and interfingering with the lumpy wackestone facies.

Lumpy wackestone

The lumpy wackestone lithofacies crops out along the track towards the SW end of the lower limestone and is best exposed at location Yar. 5 (GR of base KL 916 919). The base of the unit is in most places not exposed, except at the northern end of the outcrop where it overlies the bioclastic limestone. The upper contact with the bedded biostromal limestone is conformable but in some places difficult to pinpoint because the transition marked by increasing fossil content is gradual. The limestone is composed of lime mud with varying but typically minor shell and echinoderm debris. It is grey with weathering but dark grey to black on fresh surfaces. It has a flasery, lumpy appearance due to stylolitization with stylolites delineating small (1–5cm long, 1–3cm thick) limestone lenses. The most common biogenes are solitary horn-shaped rugose corals; towards the top small tabulate corals, alveolitids, *Amphipora* and stromatoporoids appear. The lack of bedding is due to bioturbation (Bambach and Sepkoski 1979).

Interpretation

The high mud content and lack of structures indicative of wave action suggest that the sediment was deposited in quiet water. A sample processed for total organic carbon content from this lithology and the overlying dark *Amphipora* limestone gave a low value of 0.1%. It is likely that the organic material is not preserved due to heating of the rock during burial diagenesis (P. Hoffmann pers. comm. 1997). The initial organic content cannot be determined anymore and the dark colour is probably now caused by high content of disseminated sulfides. This points to dysaerobic bottom conditions with sufficient oxygen to support the burrowing infauna. At greater sediment depth oxygen levels decreased and some detritic material escaped oxidization. The silty and argillaceous material seen on stylolitic seams suggests an original, though modest content of fine-grained terrigenous material. The sediment probably formed a soft substrate. No evidence is seen for early lithification, slow sedimentation, encrustations or discontinuity surfaces. Water depth is difficult to estimate in the absence of sedimentary structures or fossils as depth indicators. The palaeoenvironment could have been a deep shelf below fair weather wave base or the subtidal portion of a somewhat restricted marine basin.

Amphipora limestone

The *Amphipora* limestone, up to 30m thick, is best exposed at GR Klori 918 935. It is difficult to trace along strike because of structural complications and weathering; to the north and south it disappears and is obviously not laterally continuous but a subfacies within the lumpy wackestone which it overlies and interfingers with. It is succeeded by bedded biostromal limestone or by stylobreccia with red mud matrix.

The *Amphipora* limestone weathers to a dark grey colour, fresh surfaces are almost black. *Amphipora* skeletons are concentrated in 30–50cm thick banks, interbedded with equally thick beds of fine-grained dark lime mudstone or wackestone. The fossils are randomly oriented with no readily detectable palaeocurrent direction (Fig. 8C).

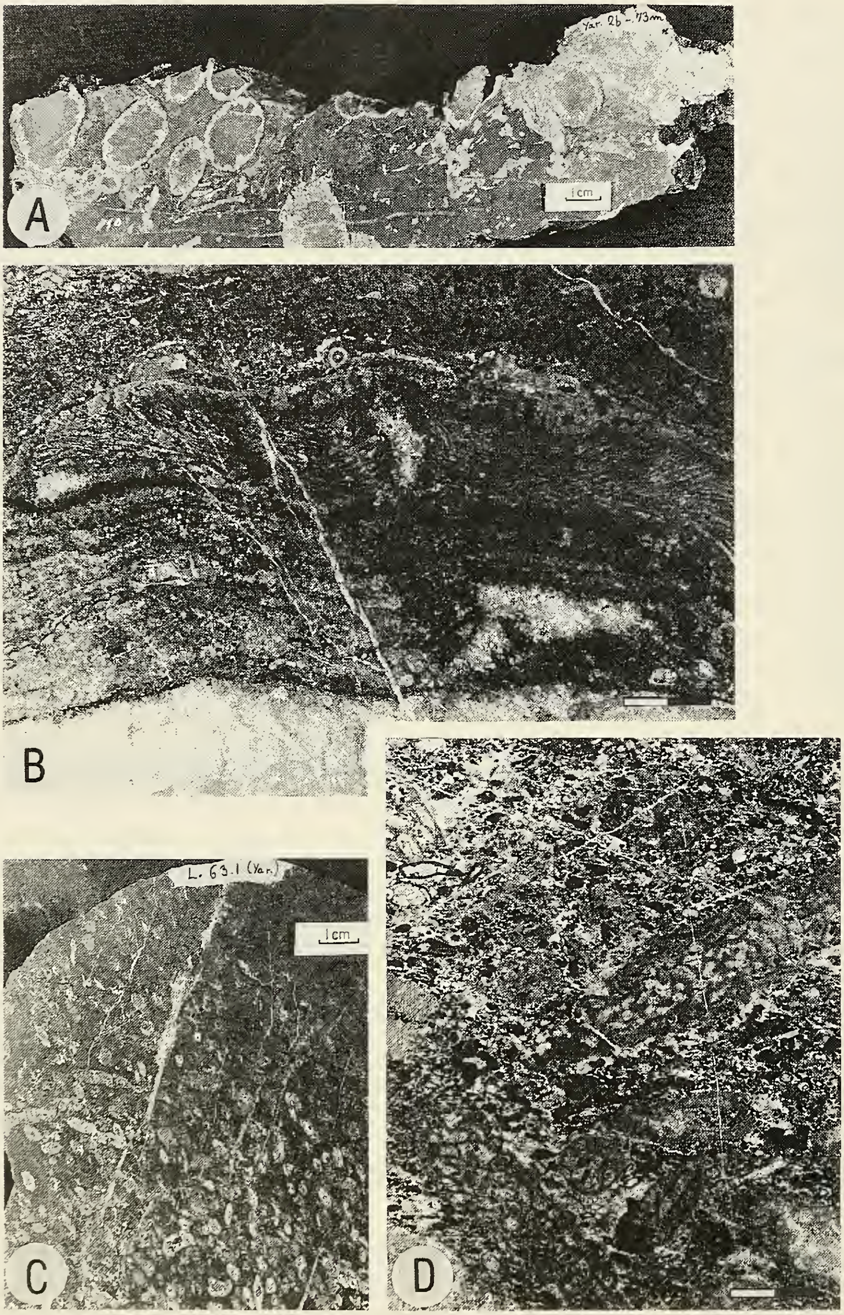

Figure 8A. Cross-sections of several colonies of *Yakutiopora* oriented parallel to bedding plane from biostrome/wackestone facies at Yar. 2, Sulcor Limestone Mbr. (Fig. 3 for location). Polished and etched slab. Scale bar is 1cm. Figure 8B. Thin section photomicrograph of partly silicified *Alveolites* colony growing on stromatoporoid. Note *Wetheredella* colony in the lower left of the stromatoporoid. Yar. 2, biostrome/wackestone facies. Scale bar is 2mm.Figure 8C. Polished slab of *Amphipora* limestone collected from Amphipora limestone unit, northern part of Sulcor Limestone Member. Figure 8D. Thin section photomicrograph of *Amphipora* coenostea set in a matrix of fine to medium grained peloidal calcarenite. Scale bar is 2mm.

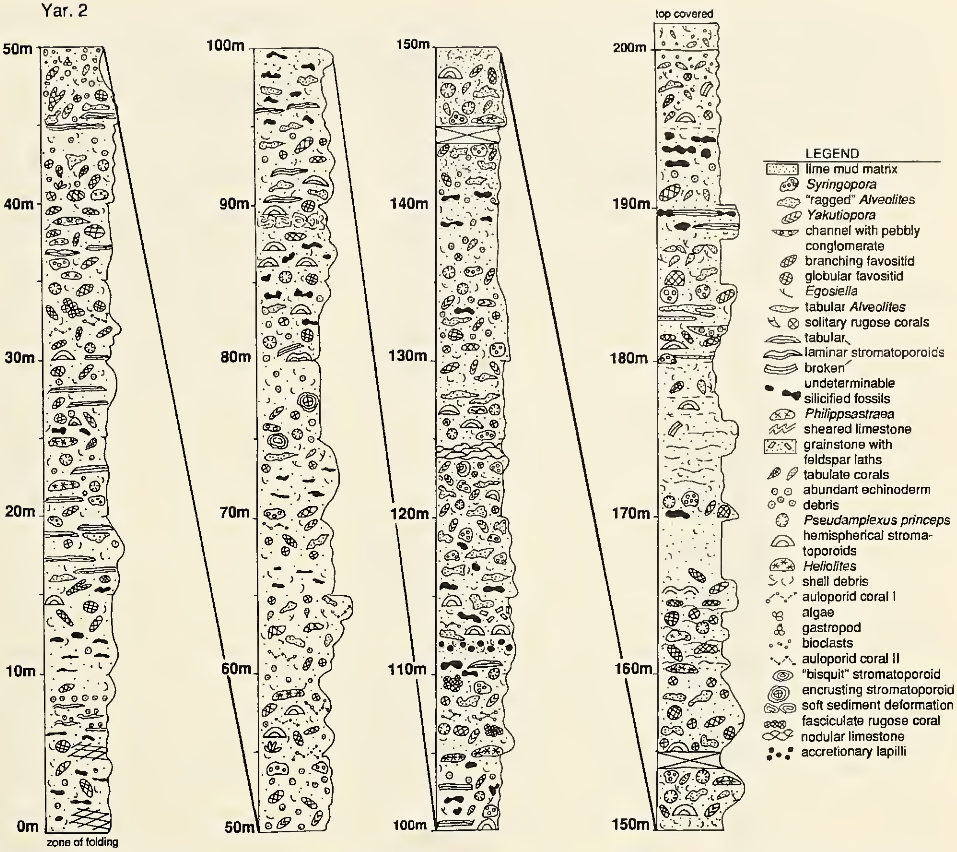

Figure 9. Section Yar. 2 measured through the central part of the Sulcor Limestone Member (see Fig. 3 for location).

In thin section the *Amphipora*-rich intervals can be classified as bafflestone and biopelmicrite (Fig. 8D). The dominant components are *Amphipora* skeletons and minor numbers of small solitary rugose corals enclosed in poorly washed, poorly sorted sand composed of medium to fine sand-sized peloids. Subordinate allochems include cortoids (=coated grains), fine shell debris, microskeletal debris and irregularly shaped algal lumps.

Fossils other than *Amphipora* include ostracods, brachiopod and echinoderm fragments, abundant small undetermined shelly fossils (single-chambered foraminifera?) and algal fragments.

Interpretation

Amphipora lived in very shallow quiet lagoons (Fischbuch 1968; St.Jean 1971) and has been reported from many such paleoenvironmental settings (Gogolczyk 1956; Gutkin and Rodchenko 1968; Jenik and Lerbekmo 1968; Fischbuch 1970; Harvard and Oldershaw 1984; Soja 1990). The accompanying components and fossils are consistent with this interpretation.

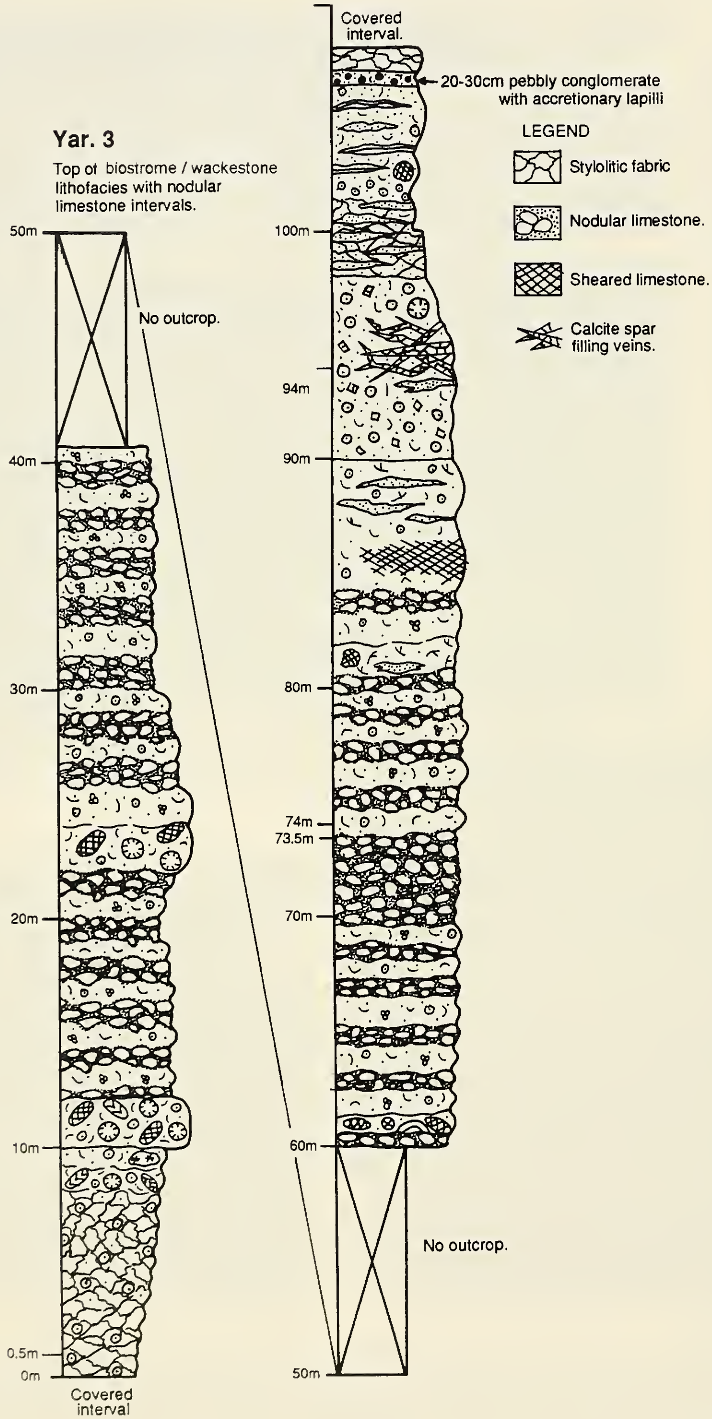

Figure 10. Section Yar. 3 through the Sulcor Limestone Member measured in bed of Yarramanbully Creek (see Fig. 3 for location; see Fig. 9 for detailed legend).

Biostrome/wackestone facies

This facies consists of pavements of tabular and laminar stromatoporoids and alveolitids interbedded with skeletal wackestone and floatstone with ramose tabulate corals. The unit is at least 150m (true thickness) thick and occupies most of the outcrop area of the Sulcor Limestone Member at Yarramanbully (Fig. 9). The sequence is well-bedded with bed thicknesses varying between 0.2m and 0.5m. It has gradual contacts with the underlying *Amphipora* limestone and dark lumpy wackestone, the upper contact with conglomerate is erosional. The limestones weather dark grey, while fresh surfaces are commonly almost black.

The lithology of the sequence is best exposed in the bed of Yarramanbully Creek at Yar. 3 (Fig. 10). Here well-washed rocks show interbedded nodular and wavy-bedded lime mudstone or wackestone (Fig. 5B) with partings of red or green mudstone.

The unit is richly fossiliferous but many of the fossils are obliterated by silicification and are seen as irregular crusts with ragged outlines emphasized by a yellow weathering siliceous rim. The 1–15cm high and 5–30cm long ragged crusts are mainly formed by alveolitids, whereas pavements are dominantly tabular stromatoporoids (Fig. 11C). Other common fossils are tabulate corals with large branching forms such as *Yakutiopora* (Fig. 8A) and favositids, fasciculate colonies of *Syringopora*, massive favositids and heliolitids, and small ramose tabulozoa of *Coenites*-type.

Rugose corals are represented by abundant *Pseudamplexus princeps* (Fig. 11D) and infrequent colonies of fasciculate and massive compound forms such as *Phacellophyllum* (Fig. 11B) and *Phillipsastrea* respectively. Sponge spicules are common but sponge skeletons are rarely preserved. Large framework-building organisms comprise between 30% and 70% of the rock volume and it is hence justified to regard the lithology as an organic build-up facies. The biogenes are embedded in a matrix of skeletal or peloidal lime mud. Fossil allochems are dominantly ostracods, filamentous shells, sponge spicules, calcite spheres, fragments of gastropods and trilobites, crinoid ossicles and fragments, debris from corals, bryozoans and stromatoporoids and, most prominently, thalli of udoteacean and dasycladale algae (Mamet and Pohler in press). Other components include peloids and cortoids. The lime mud to allochem ratio of the matrix ranges between 40 : 60 and 50 : 50.

One of the most striking features of the biostromal unit is the prolific occurrence of epibionts. Successive encrustations of thin (1–5cm) crusts of stromatoporoids or alveolitids are particularly widespread (Fig. 8B). Usually several different genera and species are involved in building encrustations which may be 10cm to several metres long. Also very abundant are diverse epibionts growing on the large tabulate and rugose corals. Corallites of *P. princeps* with an overgrowth of *Syringopora* (Fig. 11D) are a common occurrence. Other associations include growth of stromatoporoids, bryozoans or *Wetheredella* on various rugose corals, stromatoporoids on an indeterminate recrystallized encrusting organism, auloporid corals and *Trypanopora* on *Yakutiopora* and stromatoporoids. Commonly the overgrowth involves two or more different participants.

Interpretation

The biostrome/wackestone facies has been documented in detail in Pohler (1998) and is therefore only briefly addressed herein.

The growth forms of the coralline hydrozoans and tabulozoa forming thin pavements have been described from low energy backreef, reef and forereef environments in Australia's Canning Basin (Playford and Lowry 1967; Playford 1980). In the Devonian of Europe laminar stromatoporoids have been reported from forereef environments (Braun et al. 1994), reef (Jux 1960) and backreef environments (Krebs 1968, 1971; Lecompte 1970). Several researchers (Cook 1995; Yong-ji Zhen 1994; A.I. Kim pers. comm. 1993) consider the association of *Yakutiopora* and other branching tabulozoa with tabular and laminar stromatoporoids and alveolitids to be characteristic of shallow

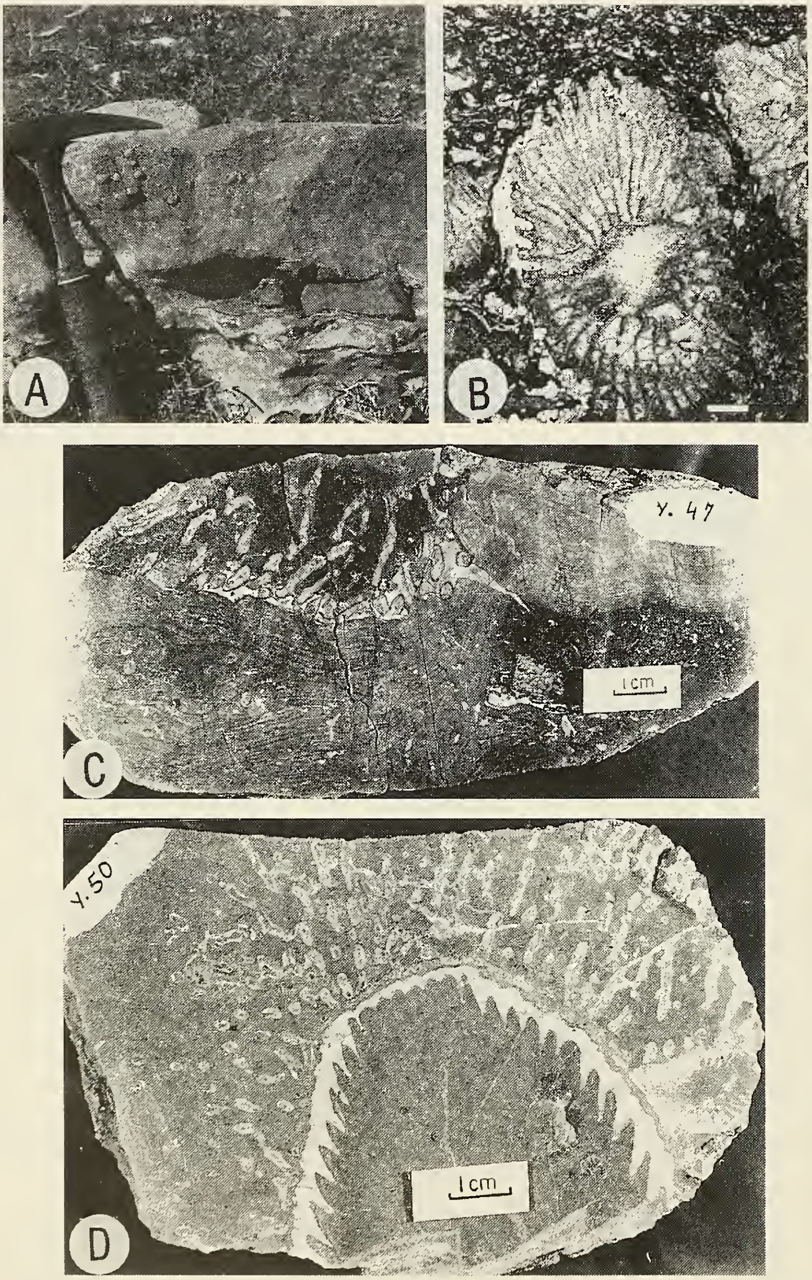

Figure 11A. Pebbly conglomerate (30cm thick) with accretionary lapilli in the creek bed of Yarramanbully Creek at the top of section Yar. 3, Sulcor Limestone Mbr. (GR Klori 902 945). Note high sphericity of lapilli. Figure 11B. Thin section photomicrograph of undetermined fasciculate colony of *Phacellophyllum* sp. which is characteristic of the biostrome/wackestone facies at section Yar. 2 (Sulcor Limestone Mbr.). Scale bar is 1mm. Figure 11C. Tabular stromatoporoid with *Syringopora* colony on top. The surrounding dark sediment is skeletal wackestone. Polished slab from biostrome/ wackestone facies at section Yar. 2. Figure 11D. Polished slab of *Syringopora* colony and juvenile rugose coral on *Pseudamplexus princeps*. Note thin stromatoporoid encrusting corallite. (Section Yar. 2).

lagoons. The abundance of lime mud (suggesting low energy), and the rich ostracod fauna and algal flora seem to support this interpretation.

In the Yarramanbully biostromes no hardgrounds are readily recognizable. In some cases a pronounced difference between sediment underlying and overlying a stromatoporoid colony can be seen, suggesting that a change in sedimentation occurred, possibly associated with a lag and induration or lithification of the surface prior to colonization. The occurrence of early carbonate cements is suggested by the remnants of aragonite needles seen in some samples. In one case a colony of *Syringopora* seems to grow contemporaneously with aragonite cements on the surface of a stromatoporoid colony (Fig. 11C). However, the presence of skeletal debris and lime mud between stromatoporoid laminae suggests that loose sediment was present and interfered with the growth of the colony. In addition, many tabular colonies are broken along vertical fractures apparently caused by differential compaction. The fractures are filled with the surrounding muddy skeletal sediment which must have been still soft in order to fill the gaps. Fractures filled with calcite spar are rarely seen.

It must be concluded that much of the sediment was colonized while still soft, and that the tabular and laminar growth could be a "snow shoe" adaptation designed to prevent the organism from sinking into the mud. Scrutton (1997) suggested that Paleozoic reef-building organisms were adapted to soft substrate. He considered the laminar and tabular growth forms of tabulate corals indicative of quiet deep water (>50–60m). Bertling (1996) suggested that the flat plate-shaped morphology of Jurassic hermatypic corals in northern Germany is an adaptation to low light intensity at depth at or below storm wave base. Some Recent hermatypic coral genera (e.g. *Montastrea*, *Porites*, *Siderastrea*) adapt to growth in deeper water by forming crustose or foliose growth forms. *Acropora* is said to form encrusting colonies under not further specified extreme conditions and generally foliose and encrusting corals are observed in low energy conditions (Milliman 1973; Sorokin 1995). Cockbain (1984) noted that in the Devonian Reef Complexes of Western Australia large massive tabular corals are common in reef margin and reef flat subfacies, whereas tabular and laminar growth forms grew on slopes and appear to be a particularly stable growth form.

Lack of light could also be due to cloudy water caused by siltation. The corals were obviously able to remove sediment from their surface. The "ragged" outline of some tabular alveolitid corals suggests that partial mortality due to sediment coverage occurred affecting the fringes of the colonies. Recovery from partial mortality also occurs in Recent corals, but constantly high turbidity tends to kill corals as can be observed in many reefs. Hence sediment coverage must have been sporadic because very flat colonies would be easily burrowed by mud and their shape was not conducive to quickly remove sediment from the surface. The bedded nature and increasing silicification of the biostrome/ wackestone also points to low sedimentation rates. Laminar and tabular growth of corals and stromatoporoids was probably not caused by low illumination due to turbid water but is rather an adaptation to increasing water depth.

<u>Conglomerates</u>

In Sulcor Limestone Member two types of conglomerates can be distinguished: a) a conglomerate with lithoclasts and b) a pebbly conglomerate with lapilli.

a) Conglomerate with lithoclasts: In the central part of the limestone body a conglomerate up to 30m thick, with subangular to subrounded carbonate and mudrock lithoclasts covers the surface of the biostrome wackestone. The conglomerate is graded with clast sizes decreasing up section. The largest clasts observed are 30cm across. The conglomerate decreases in thickness to the north.

b) Pebbly conglomerate with lapilli: A 30cm thick pebbly conglomerate occurs in the bed of Yarramanbully Creek (Yar. 3, GR Klori 902 945) (Figs 10 and 11A). The pebbles are 0.5cm–2cm in diameter, very well rounded with high sphericity and composed of siltstone with a vaguely laminated fabric reminiscent of pisolites. The matrix is a coarse to medium sand comprising a mixture of calcitic skeletal debris and volcaniclastic grains, including pyroxene, albite, and pumice. A similar pebbly conglomerate occurs in section Yar. 2c at 112m (Fig. 9). Here the pebbles are yellow-stained and cracked. A similar lithology with red siltstone pebbles occurs at Sulcor (only in loose blocks) and in the Sulcor Limestone Member in the Burdekin region (Fig. 2).

Interpretation

a) The lithoclastic conglomerates are graded suggesting that they were deposited from waning flows. The lenticular cross sections imply that channeling occurred. The increase of terrigenous material is commonly observed when shorelines become exposed due to a relative fall in sea level. As previously discussed the limestone clasts in the conglomerate are supposedly time-equivalent to the uppermost Sulcor Limestone Member. The nature of the conglomerates suggests that exposure of the shoreline occurred with subsequent erosion. This was probably caused by a fall of relative sea level as a result of either tectonic or climatic changes. The palaeogeographic setting of the limestone in a presumed forearc basin was favourable for synsedimentary tectonic events.

b) The roundness and composition of the pebbles in the pebbly conglomerate is characteristic of accretionary lapilli (R.H. Flood pers. comm. 1994; H. Noll pers. comm. 1998). In contrast to ordinary lapilli, which are clasts, accretionary lapilli are aggregations of fine ash particles. Most likely they are formed through condensation of water vapour within a highly concentrated hot pyroclastic flow or an ascending eruptive column. Water droplets acted as aggregation nuclei by making the ash particles stick together. Vapour is abundant in phreatic eruptions, occurring when the volcanic heat vaporizes a waterbody (Schumacher and Schmincke 1991). Accretionary lapilli are found in subaqueous and reworked deposits, e.g. in the Devonian Lenneporphyr of Germany (Heyckendorf 1985).

The increase of volcaniclastic material, some of it from air falls, may be interpreted as a result of renewed volcanic activity. The composition of the other volcanogenic components in the lapilli conglomerate suggests a basaltic rather than andesitic source (P. Conaghan pers. comm. 1994). The conglomerate is certainly an event horizon, but it is not clear whether one or several of these events occurred, because the horizon cannot be followed along strike to demonstrate lateral continuity.

Lower Yarrimie Formation

The conglomerate unit a) described above forms the top of the Sulcor Limestone Member. The contact with the fine-grained siltstones, siliceous mudrocks and conglomerates of the lower Yarrimie Formation is nowhere exposed contributing to the problematic nature of the relationship between siliciclastic and carbonate units. White (1988) who studied the lower Yarrimie Formation (the Lilberne Beds of Manser 1968) at the Timor anticline concluded that they are submarine fan deposits. This interpretation is also implied by lithologies and sedimentary structures of the unit below the Moore Creek Limestone Member at Jacksons Deposit (pers. obs. 1994). Exposed contacts between the Moore Creek Limestone Member and the lower Yarrimie Formation show in many cases shear zones implying bedding parallel faults. This structural displacement is likely to occur during deformation of rocks with different competence.

Moore Creek Limestone Member

The Moore Creek Limestone Member is about 200m thick and composed of two distinctive units: (1) a lower recessive weathering unit, and (2) an upper massive unit (Fig. 12).

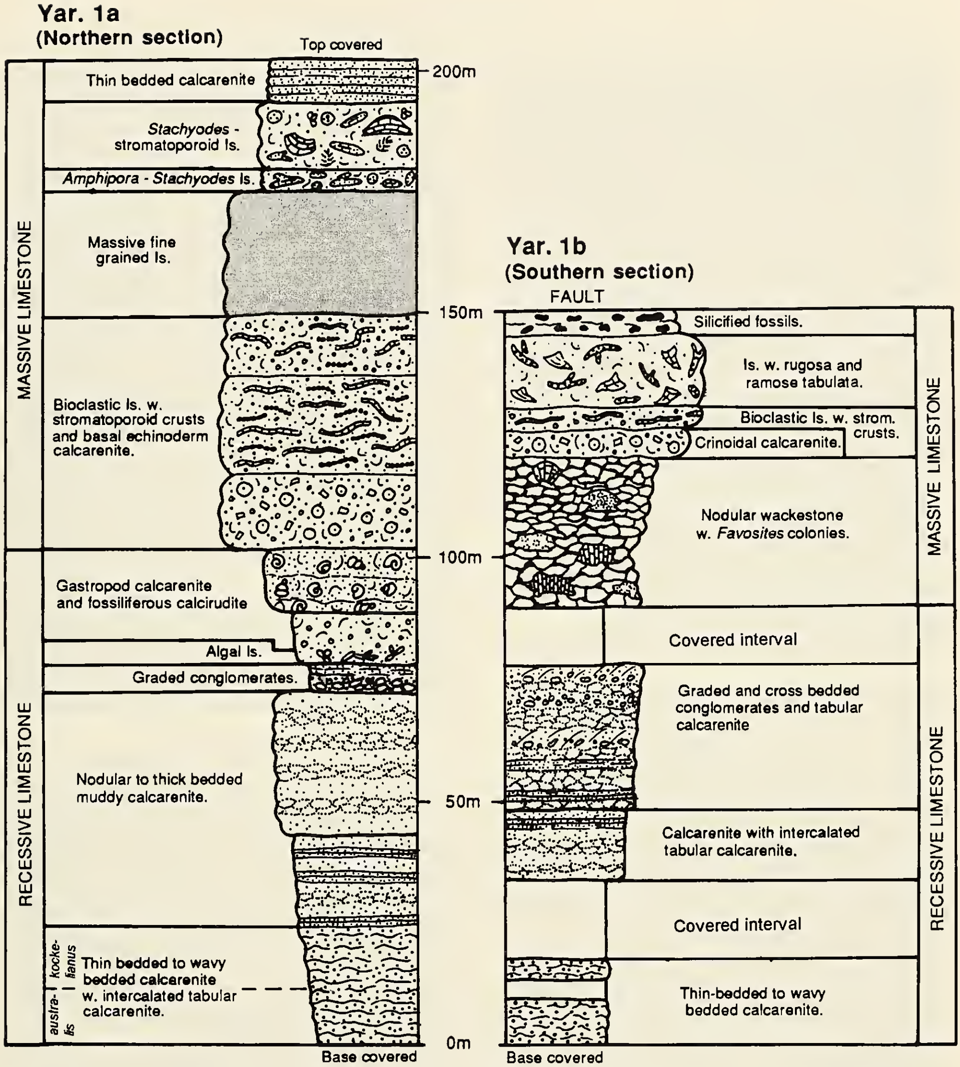

Figure 12. Measured sections Yar. 1a and Yar. 1b through Moore Creek Limestone Mbr. (see Fig. 3 for location).

The lower recessive weathering unit is characterized by a sequence of a) thin-bedded to wavy-bedded calcarenites with intercalated tabular limestone intervals, b) nodular to thick-bedded calcarenites and c) graded conglomerates, d) algal limestone, e) fossiliferous calcirudite and gastropod calcarenite.

The upper massive limestone in the north comprises a) bioclastic limestone with thin fossil crusts and basal echinoderm calcarenite, b) massive fine-grained limestone, c) *Amphipora–Stachyodes* limestone, d) *Stachyodes*- stromatoporoid limestone, and e) thin-bedded calcarenite. Southward the massive limestone sequence begins with f) nodular wackestone with *Favosites* and *Heliolites* colonies, followed by a basal echinoderm calcarenite and bioclastic limestone. Following above are: g) a bioclastic wackestone with rugose and tabulate corals and h) bedded wackestone with silicified fossils. Facies b) to e) are not developed in the south where instead facies f) to h) occur (Fig. 12). Only the bioclastic limestone with stromatoporoid crusts and basal calcarenite is common to both sections in the massive limestone unit.

(1) Lower recessive limestone unit

1a) Thin-bedded to wavy-bedded calcarenite with intercalated tabular calcarenite lithofacies

The Moore Creek Limestone Member at Yarramanbully begins with a five metre thick unit of poorly exposed 10–15cm thick beds of calcarenite with 3–5cm thick siltstone partings. The basal contact with the underlying siliciclastic unit is not exposed and the thin-bedded limestones grade upward into wavy-bedded muddy calcarenites (Fig. 14D).

The basal thin-bedded calcarenites are composed of coarse to medium sand-sized crinoid debris with very little muddy matrix. They become more vaguely bedded with 2–10mm thick partings upsection. Coarser and finer-grained beds of muddy calcarenites are intercalated and separated by wavy partings. Fossil debris is dominantly derived from crinoids; minor amounts of rugose corals and stromatoporoid fragments are also present. Around 20m up-section in Yar. 1a the amount of large silicified fossil fragments increases and partings become more pronounced. At 25.4m (Yar. 1a) 0.5–2m thick tabular bedded intervals occur. They are formed by thin (3–6cm) beds of fine calcareous and lithic sands separated by 0.5–2cm thick, dark brown siliceous ridges with a high content of siliceous silt-sized mud (Fig. 13C). The ridges outline occasional low-angle cross bedding.

Large stromatoporoid (up to 50cm diameter) and favositid colonies as well as centimetre-sized rounded mudstone pebbles are sometimes enclosed. The calcarenites have a characteristic yellow tinge from weathering of chlorite-replaced labile grains of probable volcaniclastic origin. The tabular limestones occur in 0.8m or larger intervals.

1b) Nodular to thick-bedded lithofacies

This facies begins gradually above Unit 1 and is composed of dark wackestone with light coloured echinoderm debris forming 5–20cm thick beds separated by 1–3cm thick partings which upsection become thicker and form nodular horizons. Overturned colonies of favositids and stromatoporoids can be found in some horizons (Fig. 13B).

1c) Graded conglomerate lithofacies

Graded conglomerates occur in sections Yar. 1a and Yar. 1b. Several conglomerate horizons occur in Yar. 1a between 72.1m and 78.1m. The thickest conglomerate is 50cm thick but because of the recessive weathering exposure is poor and thicker beds may be present. Each conglomerate is formed by rounded limestone pebbles, coarse fossil debris (stromatoporoids, favositid colonies, etc.) and smaller brown mudrock clast. The largest clasts are 20cm in diameter and well rounded with high sphericity. They occur usually near the base of each bed. Mudrock pebbles are usually less than 5cm in diameter and rounded but with low sphericity (Fig. 14C). Up-section the pebbles gradually decrease in size and are capped by the tabular calcarenites described above (Figs 13A, D). Deposition was apparently gradual and continuous for each graded unit because no breaks can be seen between different grain sizes. The conglomerates are laterally continuous but decrease in thickness and grain size along strike.

At Yar. 1b coarse conglomerates were not seen but several finer-grained units with decimetre thick rudites occur between 48m and 75m and may be correlative in part to the same unit in Yar. 1a. The rudites are comprised of sequences beginning with small rounded pebbles followed by cross-bedded grainstone with mud drapes and, finally, bedded grainstone without apparent sedimentary structures. They are intercalated with tabular limestone and fine grained calcarenites.

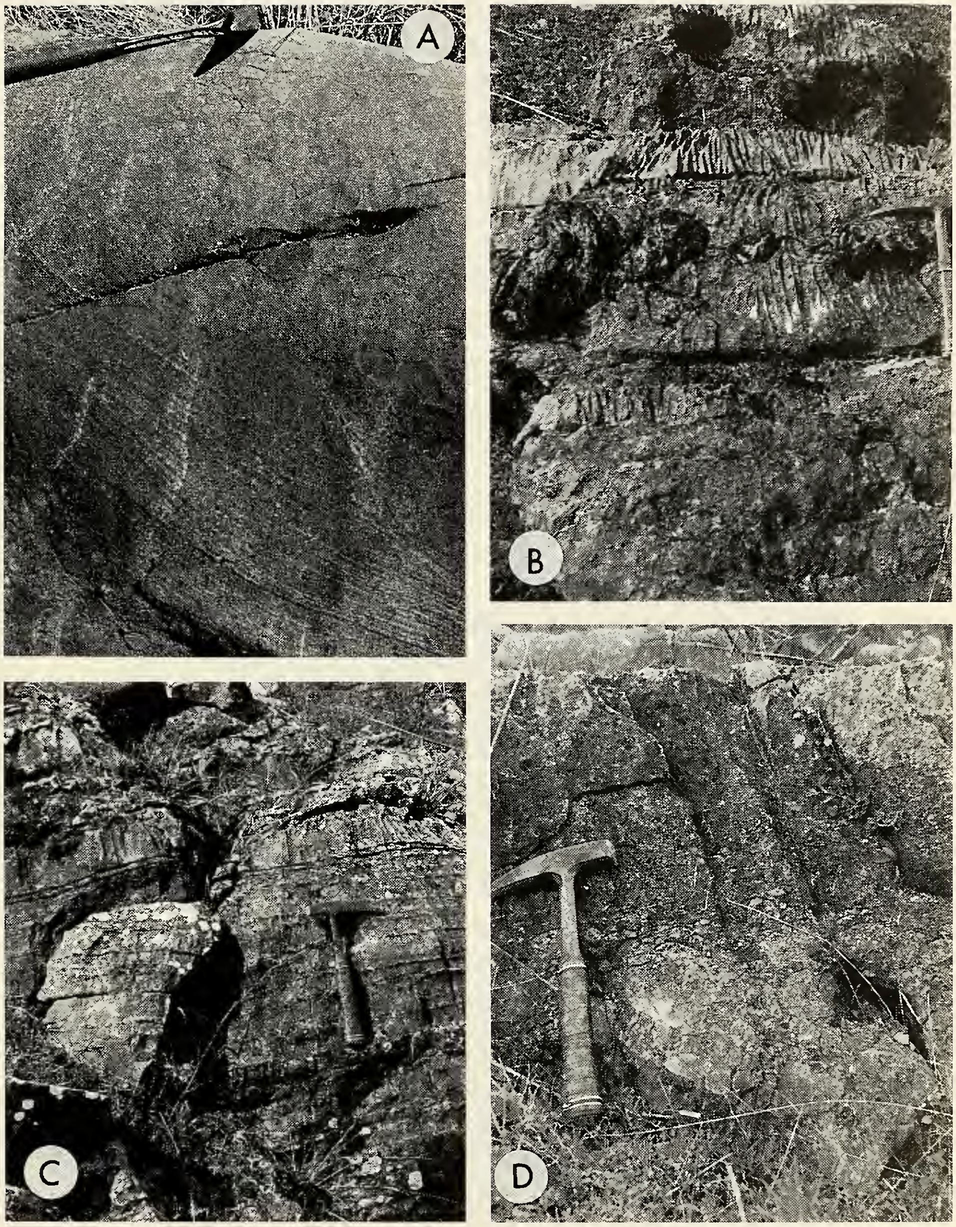

Figure 13A. Graded conglomerate with channel cutting into cross-bedded calcarenite below. At base a second graded conglomerate unit (lower left of photograph). (Moore Creek Limestone Mbr.; L. 97; Fig. 3 for location). Figure 13B. Overturned *Favosites* and stromatoporoid colonies in the nodular to thick bedded calcarenite. Section Yar. 1a, Moore Creek Ls. Mbr. Figure 13C. Platy calcarenite at section Yar. 1a with weathering resistent ridges of silicified mudrock or siltstone. Note nodular limestone above the tabular calcarenite interval. Figure 13D. Graded conglomerate at section Yar. 1a.

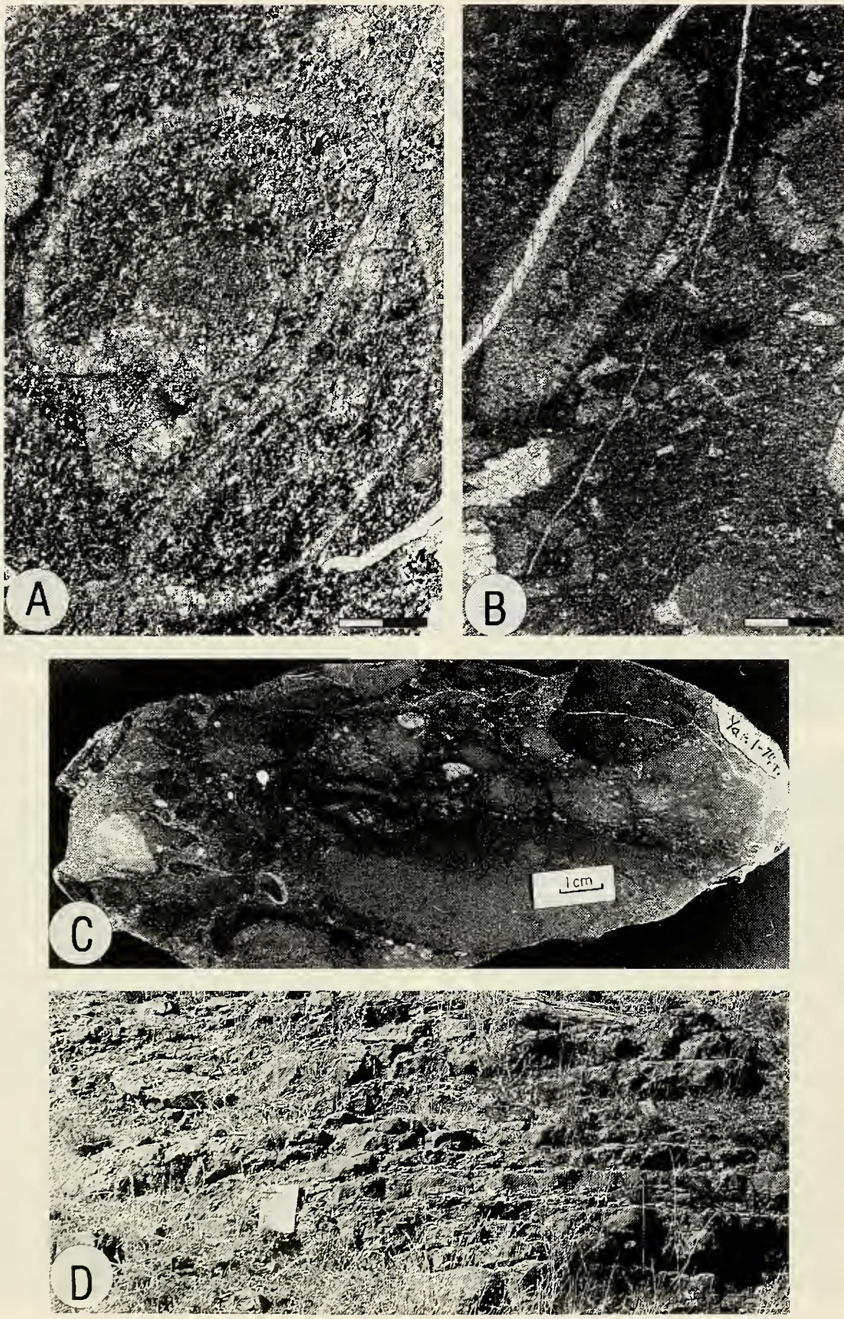

Figure 14A. Thin section photomicrograph of low-spired gastropod with shell completely replaced by calcite in fossiliferous calcarenite lithofacies. Section Yar. 1a, Moore Creek Limestone Mbr. Scale bar is 2mm. Figure 14B. Thin section photomicrograph of algal limestone at section Yar. 1a with *Couvinianella*. Scale bar is 2mm. Figure 14C. Polished slab from graded conglomerate lithofacies. Clast are rounded limestone pebbles, coarse fossil debris and smaller brown mudrock clasts. Section Yar. 1a, Moore Creek Limestone Mbr. Figure 14D. Basal thin-bedded calcarenite with siltstone partings north of section Yar. 1b, Moore Creek Ls. Mbr., Fig. 6 for location.

The matrix of the coarse conglomerates is composed of mixed siliciclastic and carbonate grainstone with much replacement by chlorite and neomorph calcite spar.

To the west in a small gully occurs a conglomerate with large, rounded lime mud pebbles overlain by cross-bedded mixed siliciclastic/carbonate sand. The beds appear to be fining upwards and in one instance the conglomerate can be seen to cut into the underlying mixed sand (Figure 13A).

The unit containing the conglomerates and tabular calcarenites can be followed throughout the map area and beyond and is hence an important marker horizon.

1d) Algal limestone

A less than 1m thick limestone bed with dasycladale algae occurs above the conglomerate unit at 79m at Yar. 1a and at the base of the northwestern side of the Moore Creek Limestone Member (GR Klori 903 947) (Mamet and Pohler in press). It contains poorly preserved thalli and molds of *Couvinianella*, a genus of dasycladacean algae described by Mamet and Préat (1992) (Fig. 14B). The outcrop is not continuous and the algae may have had a patchy distribution.

1e) Fossiliferous calcirudite and calcarenite lithofacies

The sequence is sandwiched between a short interval of algal limestone at its base and the massive limestone at its top. At section Yar. 1a it begins with 8.4m of vaguely bedded bioclastic limestone with abundant coarse fossil debris derived from stromatoporoids, *Alveolites*, and tabulate corals. This coarse unit is followed by 13.6m of wavy-bedded, yellow weathering, fine-grained calcarenite with shell-rich beds or pods of gastropods and brachiopods (Fig. 14A). This latter sequence is usually recessive and hence poorly exposed. The gastropods are low- and high-spired forms, their shells completely replaced by calcite. Trilobites and tabulate corals are also present. The matrix and surrounding calcarenite is composed of fine-grained, well-sorted peloids and rounded shell debris. The yellow weathering colour probably stems from iron oxide leached from chlorite(?) which replaced labile grains derived from volcanic tuffs.

Interpretation

Lithofacies 1a–c and e are all characterized by a largely bioclastic composition with a high percentage of lithoclasts of presumable terrigenous and/or volcaniclastic origin. The thin-bedded calcarenites at the (exposed) base of the Moore Creek Limestone Member show no cross bedding or grading; the wavy calcarenites are similarily devoid of those features. Both lithologies are moderately well sorted with a high mud content suggesting lack of winnowing. Probably transport for some distance occurred to achieve the sorting. Combined with a lack of sedimentary structures and textures indicative of traction or turbidity currents the depositional environment was probably deep subtidal (i.e. below fair weather wave base).

The tabular limestones show occasionally a pinching-out of recessive calcarenites. Grading may be expressed in the higher relief ridges caused by silicification of fine-grained argillaceous material. Weathering of volcanic tuffs to clay can form silica as a by-product (Pollock 1988). Unfortunately the rocks are too weathered to resolve their original composition by means of light microscopy. The lack of bioturbation and resulting destruction of bedding suggests that the sediment was deposited suddenly or was inhospitable for infaunal burrowers. The relatively good sorting was probably achieved by transportation, and the occasional incorporation of clastic debris along with the pinching of beds points to erosion. These parameters are suggestive of storm deposits or distal turbidites.

Flat tabular strata were defined by McKee and Weir (1953). Imbrie and Buchanan (1965) summarized the different settings where this type of stratified sediment has been observed to form: on beaches, supratidal mud flats and oolite shoals at low tide. The flat sand laminae (sheet deposits) found on supratidal mud flats were interpreted as storm deposits (Shinn and Ginsburg 1964). Similar sediments on Anticosti Island (Quebec) and Bell Island (Newfoundland) are also associated with storm deposits (pers. obs. 1989, Brenchly et al. 1993).

The graded conglomerates (1c) are characterized by rounded mudrock and limestone clasts, graded bedding, occasional cross bedding and channeling. These features are also typical of both turbidite deposits and tempestites. The roundness and composition of the clasts points to a land-to-sea direction of transport, because well-rounded clasts are usually indicative of lengthy transport or erosion and are typically found in the beach zone or at river mouths. Medium-size gravels (6–20 cm) are moved on the beach and some, together with sand, are transported into deeper water during storms (Reineck and Singh 1980). This mechanism could account for the wide distribution of the facies which can be followed southward as far as the Sulcor area. There is some indication for a sloping bottom higher up in the sequence (see below) which could support an interpretation of the graded and tabular strata as turbidites, but the great extent of the facies without facies change lends support to the interpretation as storm deposit.

The nodular to thick-bedded muddy calcarenites (1b) are very similar in composition to the wavy-bedded calcarenites and a similar environment is indicated. The nodular interbeds are probably caused by a rhythmically increased influx of terrigenous fine-grained sediment or decreased carbonate production. Bioturbation destroyed the bedding and later compaction and diagenetic unmixing may have caused the nodular fabric. The increased number of large colonies of frame-building organisms indicates a renewed colonization of the substrate by organisms other than crinoids. Maybe a decreasing amount of the terrigenous sands was the cause.

The algal limestone (1d), though not laterally continuous, is a good indicator of shallow quiet water within the photic zone. The dasycladale alga *Couvinianella* was also found in the Wyaralong limestone to the south (Pohler and Herbert 1993) at approximately the same level.

The fossiliferous calcirudites (1e) suggest increased organic diversity in a nearby area. The gastropod calcarenites are typical of shallow quiet water.

<u>(2) Upper massive limestone unit</u>

2a) Bioclastic limestone with fossil crusts

The unit is a massive grey limestone with characteristic thin wavy crusts of stromatoporoids and tabulate corals in a coarse bioclastic matrix. The sequence is over 47m thick at Yar. 1a, though much thinner at Yar 1b with conformable contacts to over- and underlying strata. The stromatoporoid crusts are 0.1–1cm thick and 2–10cm long (Fig. 15C, D). Most are redeposited but a few of the larger ones appear to be in situ. *Actinostroma, Hammatostroma,* and *Keega* are known to form thin crusts (Riding 1974). The stromatoporoid crusts are accompanied by thin lattice-shaped crusts, probably the initial layers of alveolitid corals (Fig. 15C). The crusts are associated with large *Favosites* colonies, small nodular (dislodged?) *Heliolites* (Fig. 15D), and tabular and ragged stromatoporoid and *Alveolites* colonies respectively. Large in situ fossils and fossil fragments are set in a poorly washed matrix of peloidal to skeletal packstone with abundant debris of echinoderms, ostracods, trilobites, brachiopods and algae. Intervals of coarse fossiliferous floatstone to rudstone are intercalated with better-sorted relatively unfossiliferous packstone and grainstone on a decimetre scale.

2b) Massive fine-grained limestone

The massive grey limestone is exposed in section Yar. 1a where it is 26.1m thick. It has gradual contacts with over- and underlying lithologies and is characterized by a mottled appearance and small (mm-thick and cm-long) spar-filled fissures. The mottling is

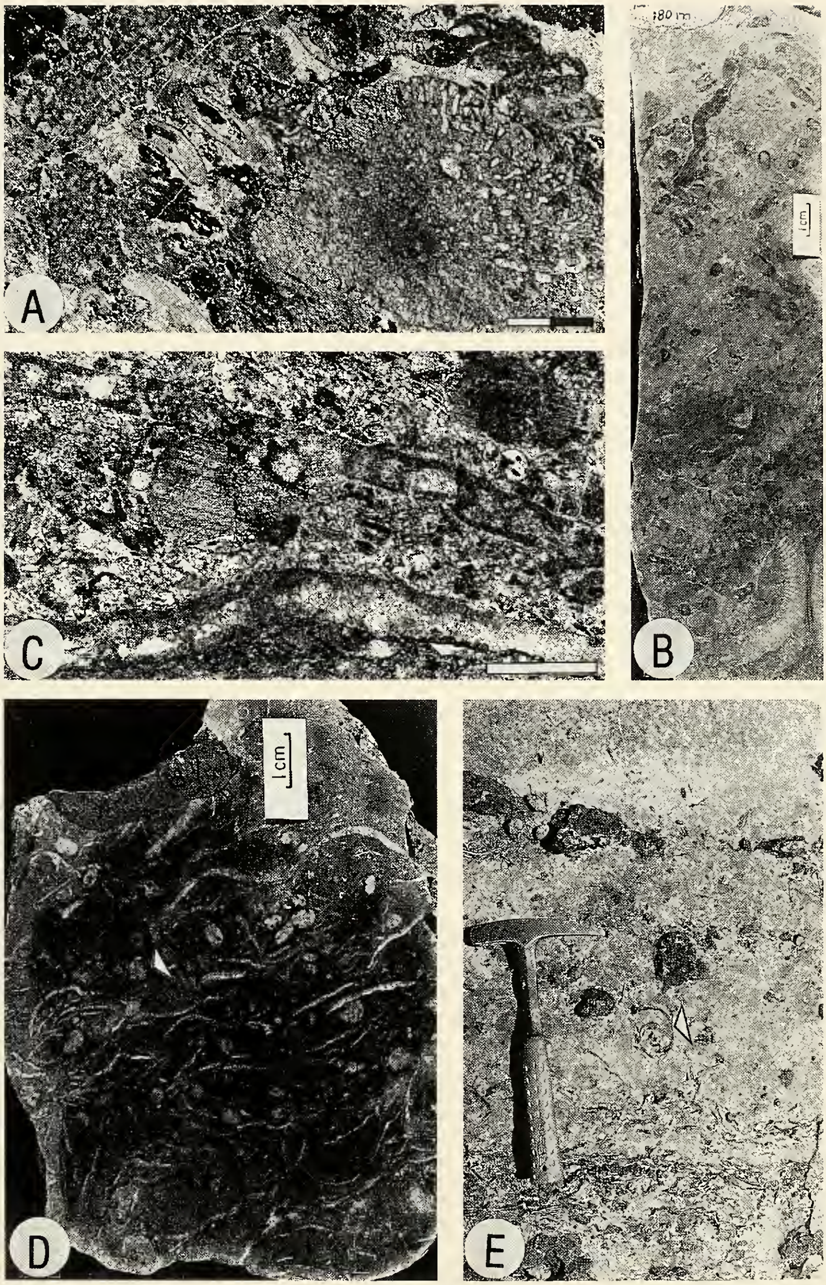

Figure 15A. Thin section photomicrograph of the *Amphipora–Stachyodes* limestone at section Yar. 1a. Moore Creek Ls. Mbr., Fig. 6 for location. Scale bar is 2mm. Figure 15B. Polished slab of *Amphipora–Stachyodes* limestone at section Yar. 1a. Figure 15C. Close-up of basal layer of alveolitid corallites from the sample Yar. 1a — 118.7m. Section Yar. 1a, Moore Creek Ls. Mbr., Fig. 6 for location. Scale bar is 0.5mm. Figure 15D. Polished slab with crusts of stromatoporoids, alveolitids (see Fig. 15C for close-up) and rounded *Heliolites* fragments (arrow) from the bioclastic limestone interval at section Yar. 1a. Figure 15E. Bedded wackestone with silicified nodules. Note goniatite to right of hammer and shell beds near base of picture. Top of section Yar. 1b, Moore Creek Ls. Mbr., Fig. 6 for location.

caused by limestone lumps (1–5cm in diameter) separated by yellow or reddish stylolitic argillaceous partings. The sediment is composed of lime mud with dark shell debris (ostracod shells) and solitary rugose corals. Patchily distributed are packstone to grainstone lenses, more coherent mudstone intervals (20cm or more across) and fossiliferous areas with *Alveolites* fragments and crinoid stems up to 3cm long. Poorly preserved *Amphipora* are scattered throughout.

2c) *Amphipora–Stachyodes* limestone

Above the massive fine-grained limestone follows a thin (1.5m) bafflestone to rudstone composed of densely-packed skeletons of *Amphipora* and *Stachyodes costulata* Lecompte (Fig. 15A, B). The skeletons are not in life position and show no preferred orientation indicating lack of current sorting. The matrix is a poorly washed peloidal packstone to wackestone with only minor skeletal debris.

2d) *Stachyodes*–stromatoporoid limestone

This 15m thick massive interval is composed of stromatoporoid and *Heliolites* colonies and associated *Stachyodes* in a matrix of bioclastic calcarenite to calcirudite with abundant algal fragments and echinoderm debris. Broken thalli of codiacean and dasycladale algae are present. The matrix is poorly washed and poorly sorted. Many of the large frame-building fossils are overturned but some appear to be in situ.

2e) Thin-bedded calcarenite

The top of the limestone succession is formed by a 9m thick interval of bedded fine to medium sand-size calcarenite.

2f) Nodular wackestone with *Favosites* and *Heliolites* colonies

Nodular wackestone is composed of oval lumps of bioclastic wackestone (3–5 cm long) set in a pink-grey matrix. The lump:matrix ratio is approximately 3:1. The basal contact with recessive limestone is covered, the upper contact with echinoderm calcarenite is gradual. The unit in section Yar. 1b is about 34m thick. It contains intermittently large (up to 40 cm diameter) in situ *Favosites* and globular *Heliolites* colonies. Bioclastic content includes minor crinoidal and brachiopod debris.

2g) Bioclastic wackestone with rugose and ramose tabulate corals

This unit is approximately 17m thick at section Yar. 1b. It is composed of bioclastic limestone with stick-like tabulate corals (abundant) and bryozoans (uncommon), rugose corals, favositids and brachiopods.

2h) Bedded bioclastic wackestone with silicified fossils

The bioclastic wackestone is characterized by large (5–8cm diameter, up to 20 cm long) lumps of silicified fossils (?). Nowhere could the origin of the lumps be ascertained but the overall shape resembles branching favositids seen in the Sulcor Limestone Member. At section Yar. 1b the unit is cut off by a fault and is only about 4–6m thick; further south it is much thicker and well bedded with abundant shell debris. At one location a goniatite of the genus *Tornoceras* was found (Fig. 15E) indicating a late Eifelian to early Givetian age of the succession (T. Becker written comm. 1997).

Facies 2f)–2h) are restricted to the southern outcrops of the Moore Creek Limestone (section Yar. 1b).

Interpretation

The bioclastic limestone with fossil crusts (2a) is composed of poorly sorted and sub-rounded bioclastic components suggesting that it was not transported far. The fossil crusts are difficult to evaluate. Playford and Lowry (1967, p.72) illustrate a sample of calcirudite with a thin stromatoporoid layer from the late Devonian Saddler Limestone (Canning Basin, W.A.). The Saddler Limestone is a forereef deposit with abundant bioclastic and biogenic components. It is possible that the stromatoporoids are fragments of larger animals or that they are dislodged juvenile colonies which attempted to colonize the unstable forereef slope. In the Moore Creek Limestone Member the stromatoporoid crusts are associated with larger colonies of in situ low hemispherical forms and other frame builders. This suggests that the crusts may also be at least partly in situ, and that they either could not grow larger because they became dislodged, or that they are dwarfed or bizarre forms which are sometimes found in hostile environments (St. Jean 1971). A coarsening of the bioclastic debris up-section without change in overall composition possibly indicates that the source area was closer. Deposition was probably in a shallow subtidal environment possibly on a sloping surface which formed an unstable substrate. This interpretation is consistent with a decreasing thickness of the unit to the south (Yar. 1b) where instead a fine-grained nodular wackestone with in situ coral colonies exists. This facies (along with facies 2h) can be followed to the southeastern corner of the Yarramanbully region. Although lacking good indicators of water depth it was probably deposited in the subtidal zone in quiet water. Both facies 2g) and 2h) were probably deposited in a similar environment. It is not clear how they relate to the section north of Yarramanbully Creek because no interfingering of the different facies can be observed due to lack of outcrop. Facies 2f)–2h) indicate a deepening upward trend progressing from nodular wackestones to bedded siliceous limestone with goniatites.

The massive fine-grained limestone (2b) with *Amphipora*, ostracods and scattered small rugose corals was probably deposited in a very quiet, possibly lagoonal, environment. As discussed above, *Amphipora* lived in shallow marine lagoons and the *Amphipora–Stachyodes* limestone (2c) was probably deposited in such an environment.

The overlying *Stachyodes*–stromatoporoid limestone with its matrix of diverse bioclastic algal debris suggests a well oxygenated marine environment within the photic zone.

The fine-grained calcarenite (2d) at the top of the sequence may be correlative to the calcarenite at the top of the Wyaralong limestone where it heralds the burial of the limestone by increasingly more siliciclastic turbidites.

The massive limestone unit begins with a large thickness of bioclastic limestone followed by fine-grained limestone with few fossils and finally a biogene-dominated limestone. Overall the sedimentation is that of a shallow marine environment, the trend being initially shallowing upwards until deposition of the *Amphipora–Stachyodes* limestone. *Stachyodes*–stromatoporoid limestone and fine-grained calcarenite seem to indicate deepening again. In the scree of the slope at Yar. 1a red ferruginous breccias with fitted clasts can be occasionally found suggesting that an erosional surface similar to that in the Wyaralong limestone is also present at the top of the Moore Creek Limestone. This erosional surface, however, has not been observed in situ.

SUMMARY AND CONCLUSIONS

The Sulcor and Moore Creek Limestone members are exposed on the eastern limb of the Yarramanbully anticline and in a number of structurally displaced bodies south of the main exposures. On the western limb younger rocks of the upper Yarrimie Formation occur, including a megaconglomerate incorporating a 300m long and 100m wide limestone block. The western limb of the anticline is downfaulted along a fault trending approximately parallel to the axis of the anticline at or near the hinge line.

The two continuous limestone belts on the eastern limb of the anticline are of different age. The lower limestone contains corals of late Emsian to possibly earliest Eifelian age and is hence time-equivalent with the Sulcor Limestone Member of the

Yarrimie Formation. The upper limestone is Eifelian to possibly Givetian in age and time-equivalent to the Moore Creek Limestone Member. The two limestones are separated by a belt of siliciclastic and volcaniclastic sediments with debris flow deposits incorporating late Emsian fossils and limestone clasts. These sediments are assigned to the lower Yarrimie Formation and are similar in lithology to those underlying the Wyaralong limestone and Jacksons Deposit. They also resemble the Lilberne Beds below the Timor Limestone Member. The contacts between lower Yarrimie Formation and lower and upper limestone members are nowhere exposed and can therefore not be evaluated with confidence.

The Moore Creek Limestone Member is overlain by brown massive and fissile siltstones, green sandstones and black and white banded siltstones of the upper Yarrimie Formation.

The Sulcor Limestone sequence begins in the north with coarse bioclastic limestone, followed by grey and black stylo-nodular mudstone to wackestone and *Amphipora* limestone. The overlying biostromal limestone comprises the thickest and most continuous unit (up to 200m). The sequence is terminated by an erosional event which is recorded by deposition of conglomerates incising the upper limestone surface. The different lithofacies are all of shallow water aspect and, with the exception of the bioclastic limestone, are quiet water deposits. The transition from *Amphipora* limestone and bioclastic limestone to bedded and partly silicified biostrome wackestone indicates a deepening upward trend consistent with the late Emsian transgression shown in Johnson et al. (1985). The restriction of the shallow water lithofacies such as the bioclastic limestone and the *Amphipora* limestone to the northern part of the map area suggests that deposition took place over a bottom sloping to the south. A bathymetric gradient is also evident in the overlying Moore Creek Limestone Member at Yarramanbully (see below) and at Wyaralong (Pohler and Herbert 1993).

The lithoclastic conglomerate that terminates the Emsian sequence could represent a gravity flow deposit which settled on top of the limestone after it was transported down slope into a basin, thus implying that the whole of the Sulcor Limestone is an olistolith. The lack of fossil data in the surrounding Yarrimie Formation hampers interpretation.

Alternatively it may indicate exposure of Sulcor Limestone to the west (?) causing erosion of biostrome wackestone and of volcaniclastic sediments. There is no indication of a karstic surface at the top of the Sulcor Limestone Member at Yarramanbully, rather the sequence records deepening upwards. This scenario would be consistent with the development of a fault scarp in the Late Emsian caused by rifting or renting of the basin floor. If the overlying lower Yarrimie Formation is in stratigraphic context it records continuing subsidence. With the data at hand it is impossible to decide whether the Sulcor Limestone Member at Yarramanbully is a fault-bounded block or an olistolith.

The Moore Creek Limestone Member begins with recessive weathering, muddy echinoderm calcarenite with high volcaniclastic content. Whether this stems from airborn tuffs or from reworked tuff horizons cannot be decided. An influx of graded conglomerates with silicified mudrock and well-rounded limestone clasts indicates erosion and reworking in the beach zone and redistribution of beach gravels by storms across the shelf area. These deposits can be traced southward, where the conglomerates are finer grained and cross-bedding becomes more prominent. The overlying algal limestone and fine-grained gastropod calcarenites confirm very shallow water as a depositional environment.

Massive bioclastic limestone with encrusting stromatoporoids and tabulate corals follow above the recessive unit. They suggest beginning stabilization of the depositional environment which enabled bottom dwelling organisms to colonize the substrate. Calciclastic components decrease further upsection with deposition of a massive fine-grained mudstone, presumably a shallow lagoonal sediment. The low fossil content implies a somewhat hostile environmment. *Amphipora–Stachyodes* limestone above indicates re-establishment of a thriving bottom community. This trend continues with deposition of the overlying *Stachyodes*- stromatoporoid limestone. Its rich algal flora indicates a shallow marine environment. Thin-bedded calcarenites form the uppermost unit of the Moore Creek Limestone and may be the first indication of termination of limestone deposition. The contact with the overlying siltstones of the upper Yarrimie Formation is not exposed. Rare occurrence of ferruginous limestone internal breccia in slope scree suggests that another erosional event occurred similar to that seen at the top of most other limestone bodies in the Tamworth Belt.

The Moore Creek Limestone further south (documented in section Yar. 1b) was probably deposited in somewhat deeper water. Particularly the bedded bioclastic wackestone with silicified fossils indicates deeper water than the presumably coeval massive limestones to the north. The southern limestone also records a deepening upward trend (beginning with deposition of the nodular wackestone) more clearly than the northern counterpart. It can be concluded that the Sulcor and Moore Creek Limestones where deposited on a sloping bottom that deepened to the south and that termination of limestone deposition coincides with relative rise of sea-level.

ACKNOWLEDGEMENTS

A grant from Macquarie University to Professor J.A. Talent and Associate Professor R. Mawson, who generously shared it, enabled this study. Many thanks also to Arkland Lime and Cement who provided field accommodation and to the mob at Wyaralong Station who assisted in many ways. Further thanks to Edward B. Stephenson for help with rock cutting, thin-sectioning and drafting. I am also grateful for the fruitful discussions with many colleagues in particular Pat Conaghan, Dick Glen, Alekseyi Kim, John Pickett, and Yong-ji Zhen who generously shared their knowledge. The continuation of the work was enabled through a grant from the DFG (Deutsche Forschungsgemeinschaft). Lastly I have to thank my mother and my brother Axel who assisted in collection of conodont samples and corals.

REFERENCES

Alexandersson, T. (1972). Micritization of carbonate particles: processes of precipitation and dissolution in modern shallow marine sediments. *Bulletin of the Geological Institution Uppsala* **3**, 201–236.

Bambach, R.K. and Sepkoski, J.J., Jr. (1979). The increasing influence of biologic activity on sedimentary stratification. *Geological Society of America Annual Meeting* **11**, 383.

Bathurst, R.G.C. (1966). Boring algae, micrite envelopes, and lithification of molluscan biosparites. *Geological Journal* **5**, 15–32.

Bathurst, R.G.C. (1975). 'Carbonate sediments and their diagenesis'. (Elsevier Scientific Publishing Company: Amsterdam).

Brenchley, P.J., Pickerill, R.K. and Strouderg, S.G. (1993). The role of wave-reworking on the architecture of storm sandstone facies, Bell Island (Lower Ordovician, eastern Newfoundland). *Sedimentology* **40**, 359–382.

Bertling, M. (1996). Ökologische und morphologische Auswirkungen von Sedimentation auf Assoziationen hermatyper Korallen im norddeutschen Oberjura. *Terra Nostra — Schriften der Alfred-Wegener-Stiftung* **6**, 22.

Braun, R., Oetken, S., Königshof, P., Kornder, L. and Wehrmann, A (1994). Development and biofacies of reef-influenced carbonates (Central Lahn Syncline, Rheinisches Schiefergebirge). *Courier des Forschungs-Institutes Senckenberg* **169**, 351–386.

Chappell, B.W. (1961). The stratigraphy and structural geology of the Manilla — Moore Creek District, NSW. *Journal and Proceedings of the Royal Society of New South Wales* **95**, 63–75.

Cockbain, A.E. (1984). Stromatoporoids from the Devonian Reef Complexes, Canning Basin, Western Australia. *Geological Survey of Western Australia, Bulletin* **129**, 108 pp.

Cook, A.G. (1995). Sedimentology and depositional environment of the Middle Devonian Big Bend Arkose and Burdekin Formation, Fanning River Group, Burdekin Subprovince, North Queensland, Australia. *Queensland Museum, Memoir* **38**, 53–91.

Crook, K.A.W. (1961). Stratigraphy of the Tamworth Group (Lower and Middle Devonian), Tamworth — Nundle District, NSW. *Journal and Proceedings of the Royal Society of New South Wales* **94**, 173–188.

Dunham, R.J. (1962). Classification of carbonate rocks according to depositional texture. In 'Classification of carbonate rocks' (Ed. W.E. HAM). *AAPG Memoir* **1**, 108–121.

Fischbuch, N.R. (1968). Stratigraphy, Devonian Swan Hills reef complexes of Central Alberta. *Canadian Society of Petroleum Geologists, Bulletin* **16**, 444–556.

Fischbuch, N.R. (1970). *Amphipora* and *Euryamphipora* (Stromatoporoidea) from the Devonian of western Canada. *Palaeontology* **13**, 64–75.

Folk, R.L. (1962). Spectral subdivision of limestone types. In 'Classification of carbonate rocks' (Ed. W.E. Ham). *AAPG Memoir* **1**, 62–84.

Folk, R.L. (1968). 'Petrology of Sedimentary Rocks'. (Hemphill Pub. Co.: Austin, Texas).

Gogolczyk, W. (1956). Rodzaj *Amphipora* w dewonie Polski. *Acta Palaeontologica Polonica* **1**, 211–240.

Gutkin, Y.S. and Rodchenko, Y.M. (1968). Formations and facies of Bauxite bearing sediments in the North Ural basin. *Sovietskaja Geologija* **5**, 21–34.

Harvard, C. and Oldershaw, A. (1984). Early diagenesis in back-reef sedimentary cycles, Snipe Lake Reef complex, Alberta. *Canadian Society of Petroleum Geologists, Bulletin* **24**, 27–69.

Heyckendorf, K. (1985). Die unterdevonischen Lenne-Vulkanite im nordöstlichen Rheinischen Schiefergebirge. Beiträge zur Stratigraphie, Petrographie und Geochemie. PhD thesis, Universität Hamburg, pp 1–363.

Hill, D. (1943). The Devonian rugose corals of the Tamworth district, NSW. *Journal and Proceedings of the Royal Society of New South Wales* **76**, 142–164.

Imbrie, J. and Buchanan, H. (1965). Sedimentary structures in modern carbonate sands of the Bahamas. *SEPM Special Publications* **12**, 149–172.

Jenik, A.J. and Lerbekmo, J.F. (1968). Facies and geometry of Swan Hills Reef Member of Beaverhill Lake Formation (Upper Devonian), Goose River field, Alberta, Canada. *AAPG Bulletin* **52**, 21–56.

Johnson, J.G., Klapper, G. and Sandberg, C.A. (1985). Devonian eustatic fluctuations in Euramerica. *Geological Society of America Bulletin* **96**, 567–587.

Jux, U. (1960). Die devonischen Riffe im Rheinischen Schiefergebirge. *Neues Jahrbuch für Geologie, Abhandlungen* **110**, 186–392.

Krebs, W. (1968). Reef development in the Devonian of the eastern Rhenish Slate Mountains, Germany. In 'International Symposium on the Devonian System, Calgary, Canada' (Ed. D.E. Oswald) **v. II**, pp.295–306. (Alberta Society of Petroleum Geologists: Calgary).

Krebs, W. (1971). Devonian reef limestone in the eastern Rhenish Schiefergebirge.In 'Sedimentology of parts of Central Europe' (Ed. G. Müller) *Guidebook* **8**, 45–89. (Frankfurt: Kramer).

Lecompte, M. (1970). Die Riffe im Devon der Ardennen und ihre Bildungsbedingungen. *Geologica et Palaeontologica* **4**, 25–71.

Mamet, B. and Préat, A. (1992). Algues du Devonien Moyen de Wellin (Synclinorium de Dinant, Belgique). *Revue de Micropaleontologie* **35**, 53–75.

Mamet, B. and Pohler, S.M.L. (in press). Algae from Early to Middle Devonian limestones, Tamworth Belt, NSW, Australia. *Alcheringa*.

Manser, W. (1968). Geological map of New England 1 : 100 000 Wingen sheet (No. 359 and parts of 350, 351 and 360) with marginal text and 1 : 50 000 Timor Anticline. (University of New England Press: Armidale).

Marshall, A.J. (1968). Stratigraphy of the Yarramanbully area near Manilla, NSW. BSc. (Hons.) thesis, University of New England, Armidale.

Mawson, R., Pang, D. and Talent, J.A. (1997). G.J. Hinde's (1899) Devonian radiolarians from Tamworth, north-eastern New South Wales: Stratigraphic and chronologic context. *Proceedings of the Royal Society of Victoria* **109**, 133–256.

Mawson, R. and Talent, J.A. (1994). The Tamworth Group (mid-Devonian) at Attunga, New South Wales, conodont data and inferred ages. *Courier des Forschungs-Institutes Senckenberg* **168**, 37–58.

Mawson, R., Talent, J.A., Bear, V.C., Benson, D.S., Brock, G.A., Farrell, J.R., Hyland, K.A., Pyemont, B.D., Sloan, T.R., Sorentino, L., Stewart, M.I., Trotter, J.A., Wilson, G.A. and Simpson, A.G. (1988). Conodont data in relation to the resolution of stage and zonal boundaries for the Devonian in Australia. *Canadian Society of Petroleum Geologists, Bulletin* **14**, 485–527.

McKee, E.D. and Weir, G.W. (1953). Terminology for stratification and crosstratification in sedimentary rocks. *Geological Society of America Bulltetin* **64**, 381–390.

McMinn, A. (1977). Sedimentology and stratigraphy of the Tamworth and Baldwin Groups in the Yarramanbully district, western New England Fold Belt. BSc. (Hons.) thesis, Sydney University, Sydney.

McMinn, A. (1982). The age and facies distribution of the Yarrimie and Baldwin formations in the Manilla district. In 'New England Geology' (Eds P.G. Flood and P. Runnegar) pp. 113–120. (Department of Geology of UNE and ANU Club: Armidale).

Milliman, J.D. (1973). Caribbean Coral reefs. In 'Biology and Geology of Coral Reefs' (Eds O.A. Jones and R. Endean) pp. 1–50. (Academic Press, Inc.: New York, London).

Pedder, A.E.H. (1970). Studies in the Devonian tetracoral faunas of Tasmania, Victoria and New South Wales. PhD thesis, University of New England, Armidale, **vol.1**, 357 pp.

Pedder, A.E.H. (1967). The Devonian System of New England, New South Wales, Australia. In 'International Symposium on the Devonian System, Calgary, Canada' (Ed. D.E. Oswald) **v. II**, pp.135–142. (Alberta Society of Petroleum Geologists: Calgary).

Pettijohn, F.J. (1957). 'Sedimentary Rocks'. (Harper and Row, Second Edition: New York, Evanston, and London).

Philip, G.M. (1967). Middle Devonian conodonts from the Moore Creek limestone, northern New South Wales. *Journal and Proceedings of the Royal Society of New South Wales* **110**, 151–161.

Philip, G.M. and Pedder, A.E.H. (1967). Stratigraphical correlation of the principal Devonian Limestone sequences of Eastern Australia. In 'International Symposium on the Devonian System, Calgary, Canada' (Ed. D.E. Oswald) **v. II**, pp.1025–1041. (Alberta Society of Petroleum Geologists: Calgary).

Playford, P.E. (1980). Devonian "Great Barrier Reef" of Canning Basin, Western Australia. *AAPG Bulletin* **64**, 814–840.

Playford, P.E. and Lowry, D.C. (1967) Devonian reef complexes of the Canning Basin, Western Australia. *Geological Survey of Western Australia, Bulletin* **118**, 1–150.

Pohler, S.M.L. (1998). Devonian carbonate buildup facies in an intra-oceanic island arc (Tamworth Belt, N.S.W., Australia). *Facies* **39**, 1–34.

Pohler, S.M.L. and Herbert, C. (1993). Carbonate sedimentology of the Middle Devonian Wyaralong limestone near Attunga, NSW. *Association of Australasian Palaeontologists, Memoir* **15**, 255–278.

Pollock, S.G. (1988). Chert formation in an Ordovician volcanic arc. *Journal of sedimentary Petrology* **57**, 75–87.

Reineck, H.E. and Singh, I.B. (1980). 'Depositional sedimentary environments'. (Springer Verlag: Berlin, Heidelberg, New York).

Riding, R. (1974). The Devonian genus *Keega* (algae) reinterpreted as a stromatoporoid basal layer. *Palaeontology* **17**, 565–577.

Schumacher and Schmincke (1991). Internal structure and occurrence of accretionary lapilli — a case study at Laacher See Volcano. *Bulletin of Volcanology* **53**, 612–634.

Scrutton, C.T. (1997). Growth strategies and colonial form in tabulate corals. *Real Sociedad Espanola de Historia Geologia (Sec. Geol.), Boletin* **91**, 179–191.

Soja, C.M. (1990). Bathymetric gradient within a Paleozoic island arc, southeastern Alaska (Alexander Terrane). *AAPG Bulletin* **74**, 767–768.

Sorokin, Y.I. (1995). 'Coral Reef Ecology'. *Ecological Studies*, **Vol. 2**, 465 pp. (Springer Verlag: New York).

St. Jean, J. (1971). Paleobiologic considerations of reef stromatoporoids. In 'Proceedings of the North American Paleontological Convention: Lawrence, Kansas' (Ed. E.L. Yochelson, **Vol. 2**, Part J, 1389–1429. (Allen Press Inc.).

Voisey, A.H. (1958). The Manilla Syncline and associated faults. *Journal and Proceedings of the Royal Society of New South Wales* **91**, 204–214.

White, M.J. (1988). Stratigraphy, structure and sedimentology of the Devonian sequence in the lower Perry's Creek district, southwest New England Fold Belt. B.Sc. thesis, University of Technology, Sydney.

Zhen, Y. (1994): Succession of coral associations during a Givetian transgressive-regressive cycle in Queensland. *Acta Palaeontologica Polonica* **41**, 59–88.